December 2014

2013 Great Salt Lake Fringe Wetland Survey

Purpose: FY2010-WPDG :: Develop monitoring and assessment (M&A) framework for GSL fringe wetlands (FRNG)

Contract: CD968114-01

Table of Contents

List of Tables

List of Figures and Maps

1.0 Introduction

An extensive band of lacustrine marsh lies adjacent to the dynamic shoreline of the eastern portion of Great Salt Lake (GSL). These highly productive wetlands serve as a terminal freshwater ecosystem along the perimeter of hypersaline GSL, and support a substantial population of waterfowl and shorebirds that visit the lake each year. These wetlands also serve as a final physical and biogeochemical filter for sediments, nutrients, and trace metals released from point and non-point sources by the rapidly growing Wasatch Front, before discharging to mudflats and open water portions of the lake. As such, there is a clear need to develop assessment tools and a monitoring framework to evaluate and protect the health of these ecosystems. While definitions vary, healthy fringe wetlands should provide habitat and food-source support for avian aquatic life and maintain the capacity to retain sediments, immobilize nutrients, and sequester trace metals from surface waters prior to reaching the lake.

The objective of this project was to aid the development of an assessment method for fringe wetlands associated with Great Salt Lake (GSL). Goals for this assessment project include: (i) improve wetland sampling procedures and analytical techniques to support evaluation of important biological response and stressor indicators, (ii) develop techniques to characterize good versus poor conditions across the GSL basin for a variety of physical, chemical, and biological features, including plant, aquatic macroinvertebrate, and algal communities, and (ii) develop methods to assess wetland assimilative capacity and ecological integrity for specific fringe wetland areas that receive treated effluent from adjacent wastewater treatment facilities, *with the goal of maintaining the assimilative capacity*.

1.1 Project Background

Investigation of GSL wetlands by Utah's Division of Water Quality (DWQ) began in 2004 in response to stakeholder concerns that nutrient loads from water treatment facilities adjacent to GSL may have deleterious impacts on these productive and highly valued ecosystems (CH2MHill, 2006). Initial work focused on Farmington Bay and adjacent wetlands, where wetland managers and conservation groups observed the occasional dominance of cyanobacterial mats (Miller and Hoven, 2007), a common indicator of phosphorus-induced eutrophication (Reddy and DeLaune, 2008). The concern was that these mats could negatively impact the health and vigor of desirable characteristic wetland features, such as submerged aquatic vegetation (SAV) (e.g., sego pondweed, Stuckenia sp.), or alter the species composition of macroinvertebrate communities. Both SAV and benthic macroinvertebrates are key food sources for migratory water birds (Miller and Hoven, 2007; Keddy, 2010) and important ecological components of freshwater wetlands.

GSL wetland classes range from marginal saltgrass-dominated meadows to extensive permanently flooded ponds (Ducks Unlimited, 2008; Emerson and Hooker, 2011), with distinct biological communities and ecosystem processes (Smith et al., 1995; Mitsch and Gosselink, 2007; Keddy, 2010), similar to those found in other large-scale wetland complexes (Albert et al., 2005; Johnston et al., 2007; Cooper et al., 2013). A large proportion of impounded wetlands and associated fringe wetlands (FRNG) adjacent to GSL are managed for waterfowl and other wetland-associated avian species by the Division of Wildlife Resources as Waterfowl Management Areas (WMAs), the United States Fish and Wildlife Service's Bear River Migratory Bird Refuge (BRMBR), and other public and private entities. Wetlands within these management areas have specifically designated water quality protections (Utah Administrative Code [UAC] R317-2-13.9 [Link]) to support "waterfowl, shorebirds and other water-oriented wildlife . . . including necessary aquatic organisms in their food chain" (UAC R317-2-6). However, similar wetland types that occur outside the boundaries of state or federal management areas are not currently afforded specific numeric water quality protections; rather, they are protected by the narrative standards soley based on their geographic location within the lake. The development of appropriate and sensitive assessment methods for the dominant classes of GSL wetlands will support the establishment of wetland-specific water quality standards (WQS), and provide both regulatory clarity and environmental protection for Utah's Great Salt Lake ecosystem.

GSL wetlands are dominated by two main wetland classes: Impounded wetlands (IW) and fringe wetlands (FRNG). Impounded wetlands represent areas where dikes, berms, ditches, and culverts have been constructed to control the inflow and outflow of water through wetlands. These wetlands are entirely human-made and occur as large, shallow ponds that range in size from 20 to over 1,000 acres (Miller and Hoven, 2007). GSL IWs encompass approximately 100,000 acres and are actively managed by both state and federal agencies as well as private duck hunting clubs for waterfowl habitat.

Fringe wetlands typically occur where freshwater flows over very gently sloping portions of the exposed lakebed. Fringe wetlands are found below freshwater sources to GSL, including outlets from IWs, wastewater treatment facility discharges, and other natural and artificial low-gradient surface channels or small streams. These wetlands are commonly vegetated by tall emergent marsh plant communities; however, shallow open water and hemi-marsh cover types also occur. Depending on the quantity of water flow and lake elevation, fringe wetlands can span from the border of IWs to the margin of GSL itself. As such, these wetland systems are the last opportunity to immobilize, transform, or remove contaminants from surface waters prior to entering GSL. Fringe wetlands adjacent to GSL encompass approximately 300,000 acres and are not typically managed by state and federal agencies, or by private hunting clubs for waterbird habitat.

Current wetland assessment and reporting efforts are intended to support appropriate water quality standards as part of an adaptive wetland monitoring and assessment program for Great Salt Lake Wetlands. DWQ's short-term goal is to develop an assessment framework for fringe wetlands that is similar to that being refined for impounded wetlands (DWQ, 2012 and 2014). This preliminary sampling effort (2013 field season) helped refine sampling methods and generate environmental data to better understand which characteristics of fringe wetlands best represent ecosystem response to stress. An important element of this project is the development of an appropriate definition of the fringe wetland class that is suitable for probabilistic sampling designs and relevant to the health of GSL.

Fringe wetlands sampled in this project were described as predominantly emergent wetlands adjacent to GSL with shallow, fresh surface water inflows. Previous work commonly referred to these systems as "sheetflow wetlands."

1.2 Nomenclature of Great Salt Lake Fringe Wetlands

The nomenclature of "fringe wetlands" has evolved over the last ten years as research and classification schemes for wetlands of GSL have developed. Clarifying how the term "fringe wetlands" is used, and the spatial and ecological context for sites it describes, is important to understanding and interpreting previous work completed by various researchers and in framing new efforts by DWQ to assess the condition of GSL wetlands.

Efforts to characterize GSL wetlands are focused on two dominant classes of wetlands, impounded and sheetflow wetlands (defined in DWQ, 2012; DWQ, 2013). These wetland classes support a great abundance of migratory and resident waterfowl and shorebirds, and may be affected by discharges from wastewater treatment plants and other point- and nonpoint sources. As data from previous studies were evaluated, especially in the context of the surrounding landscape, the term fringe wetlands began to be used to describe nearly flat, emergent to hemi-marsh wetlands located within the transition zone between freshwater sources and hypersaline waters of GSL (DWQ 2009 and 2010). The use of the term fringe wetlands gained momentum as researchers began to more frequently use a hydrogeomorphic (HGM) approach to evaluate the function of GSL wetlands.

- Sumner et al. (2010) formally created a fringe wetlands class for GSL by consolidating four templates in the National Wetlands Inventory (NWI) functional wetland classification system into a single class—fringe wetlands. Fringe wetlands were wetlands where the GSL water elevation "maintains the water table in the wetland." Wetlands in the emergent wetlands template, by contrast, "are generally found in association with the discharge of groundwater to the land surface or sites with saturated overflow with no channel formation" (Sumner et al., 2010). It is the latter, the emergent wetlands class, where most of the original sheetflow wetland sites fall.

- Emerson and Hooker (2011) updated Sumner et al.'s (2010) classification system for Bear River Bay with the goal of simplifying and improving the interpretation of the impounded wetlands of GSL. The GSL wetland classification system includes high fringe and low fringe wetland classes that are directly linked to GSL water elevations. The emergent wetland class is associated with groundwater discharge and surface water flows. Thus, sheetflow wetland sites, under the Emerson and Hooker classification system, also fall within the emergent wetland class.

As DWQ develops an assessment framework for GSL fringe wetlands, it is important to maintain clear and consistent descriptions of targeted wetland classes that reflect project objectives. Sites targeted by DWQ's 2013 preliminary fringe wetland condition assessment specifically focus on understanding the condition of wetlands that have developed from GSL mudflats in response to freshwater surface inflow (DWQ 2013). These sites may also be influenced by groundwater and lake water elevations, but the surface freshwater inflow is considered a key feature for this class. Fringe wetland sites in this study are structurally similar to other emergent marsh wetlands described in Sumner et al. (2010) and Emerson and Hooker (2011), and sheetflow wetlands as previously (CH2MHILL, 2005; CH2MHILL, 2006; Miller and Hoven 2007) and currently described (Carling et al., 2013).

1.3 Specific Project Objectives

As touched on briefly above, a primary goal for the assessment of GSL fringe wetlands involves developing field sampling methods and analytical approaches to distinguish good versus poor condition (i.e. relative health) based on multiple ecological characteristics. These characteristics should support aquatic wildlife, such as the composition of plant, aquatic macroinvertebrate, or algal communities, while field sampling should capture a gradient of biological condition relating to key stressors or pollutants. An assessment framework for fringe wetlands would then be used to support monitoring of wetlands that are currently dominated by, and possibly dependent on, the direct discharge of treated effluent from wastewater treatment facilities. Ultimately, as the state and stakeholders gain experience and confidence applying the assessment framework, basin-wide monitoring efforts will report on the condition of fringe wetlands among watersheds in Utah's 305(b) *Integrated Report*. In addition, project-specific monitoring efforts can be developed to support compensatory mitigation requirements or water quality-based restoration projects as necessary.

The current project includes the following tasks:

(i) Develop monitoring network of FRNG wetlands along disturbance gradients. *Build on the historical collection of FRNG sites (as described in CH2MHill, 2005; 2006)*
(ii) Select (and improve) appropriate indicators of ecological condition (physical, chemical, and biological). *Preliminary literature review of potential metrics (CH2MHill, 2014)*
(iii) Develop and improve field methods for indicators (modified and updated SOPs and SAPs). *Build on previously developed SOPs (Draft documents here: Link)*
(iv) Statistical analysis of indicator data to derive responsive metrics

1.4 Wetland Assessment

Monitoring, Assessment and Reporting are essential elements of DWQ's environmental protection programs such as permitting and compliance. Similar to the efforts for streams and lakes, DWQ's Wetland program provides data on ambient conditions to support monitoring, assessment and reporting for wetlands.

For wetland assessments, there has been a distinction between efforts to evaluate wetland *condition* or *ecological integrity* (Fennessy et al., 2007; Stein et al., 2009a; Menuz et al., 2014;) as opposed to wetland *function* (Brinson, 1996; Wardrop et al., 2007; Jacobs et al., 2010). Wetland condition scores are evaluated as deviations from measured or modeled values for similarly classified wetlands that lack human alterations, or as departures from 'naturalness' (Menuz et al., 2014), while functional assessments are evaluated for specific processes or functional capacities relative to an undisturbed collection of reference standard sites (Smith et al., 1995). However, one weakness of the condition approach is that wetlands with the lowest degree of alteration (i.e. expected highest condition) do not necessarily represent the highest level of wetland functions (Hruby, 2001).

Much of the work on wetland condition is focused on emergent plant communities and development of biological indicators (*sensu* Indices of Biotic Integrity (IBI) and Floristic Quality Assessment (FQA)) that respond to landscape-scale stressors (Lemly and Gilligan, 2013; Rocchio and Crawford, 2013; Menuz et al., 2014). The central element of a plant community-based IBI or FQA is the concept of '*conservatism*' of plant species, where sensitive species have high fidelity to undisturbed conditions while other, more cosmopolitan species have a high tolerance for disturbance. In contrast, work focused on wetland functions commonly utilizes more structural attributes of wetlands (e.g. abundance of various plant strata, occurrence of alterations to a stream channel; see Jacobs et al. 2010). However, differences in variable selection between these two approaches are small. Larger differences between functional and condition assessments result from whether individual functions (or ecological attributes) are compared to reference standard sites, as opposed to similar comparisons after multiple attributes of condition have been aggregated. For example, functional assessments emphasize performance of individual functions (relative to reference standards), while condition assessments generate a more integrated view of the site that aggregates multiple functions (Stein et al., 2009b). This distinction can be important, since sites with greatest ecological condition (or integrity) may not necessarily have the highest scores for all possible wetland functions (Hruby, 2001).

A third approach to wetland assessment is conceptually derived from stream biological assessments, where various elements of biological response (e.g. metrics of community composition, indicator taxa, or multi-metric indices (MMI)) are related to both reference standard conditions and a gradient of stress (or chemical exposure) (Lougheed et al., 2007; Cvetkovic and Chow-Fraser, 2011). Work by DWQ to assess GSL wetlands relies on knowledge developed by all three approaches to wetland assessment, but our goal of ultimately developing water quality standards (WQS) for wetlands, by clarifying wetland designated uses and establishing narrative and numeric criteria to support those uses, is most closely tied to the biological assessment work.

Specifically, work by DWQ to assess FRNG wetlands relates to both (i) an assessment of ambient condition (i.e. relative health) throughout the GSL basin, as well as (ii) an assessment of whether the appropriate designated uses (e.g. aquatic wildlife (waterfowl and shorebirds)) for specific effluent-dominated sites are supported. As such, 'good condition' or 'high functioning' fringe wetlands support and maintain a robust degree of ecological complexity (as determined by comparison of biological communities against reference standard sites) and an assimilative capacity that serves to protect the designated uses of more sensitive downstream systems (as determined by changes in community composition and biogeochemical / metabolic indicators across a disturbance (or exposure) gradient).

1.4.1 Reference Standard Condition and the Disturbance Gradient

Biological assessment of aquatic resources, including wetlands, rely primarily on three key components. The first component is the development of one or more integrated measures of biological integrity; most commonly derived from the taxonomic composition of aquatic communities, such as algae (phytoplankton, periphyton or diatoms), amphibians, macroinvertebrates or plants. The second component involves the identification, characterization and classification of the resource (e.g. fringe wetlands or lacustrine marsh), including unaltered (or least disturbed) reference standard sites that can be used as the baseline for all site comparisons within a given ecosystem type. Lastly, the third component consists of an appropriate probabilistic survey design that allows for generalization of wetland health at the watershed scale (Stevens and Jensen, 2007). This report summarizes current efforts to assess fringe wetlands (component 1). DWQ is working with Utah Geological Survey (UGS) scientists on updating the classification and mapping of GSL wetlands, and is also developing a network of potential reference standard sites for both fringe and impounded wetlands with the GSL basin (component 2). A probabilistic survey (component 3) will be designed once the assessment method has been more fully developed and tested, and an appropriate and useful fringe wetland sample frame is constructed.

There are two aspects of assessment for GSL wetlands that complicate the process of methods development. First, wetlands associated with GSL have been intensively managed, and even created, for a variety of purposes (uses) over the last century. These wetlands have received a wide range of sediment, nutrient and other pollutant loads from agricultural, urban and industrial sources as the eastern shore of GSL became more developed. As such, there is no *a priori* set of reference standard sites that represent the highest degree of ecological integrity (*sensu* Stoddard et al., 2006) adjacent to GSL for comparison. DWQ is working to identify potential reference standard wetlands farther afield, away from specific activities or discharges that may have degraded wetlands within the GSL assessment area. Two areas have been identified where wetlands are likely to have received a lower level of historic and contemporary disturbances; wetlands associated with Fish Springs National Wildlife Refuge (NWR), and wetlands within Snake Valley (a remote area of Utah's West Desert). Both areas are within the historic extent of Lake Bonneville, have broadly similar plant communities, and contain a similar range of water salinity as wetlands more closely associated with Great Salt Lake. Field sampling is on-going (2014-2016) to capture the range of natural variability of these systems. Results from this work will be incorporated into assessments for both fringe and impounded wetlands.

A second complication results from the significant degree of hydrologic modification found within the eastern portion of the Great Salt Lake basin. Water is routinely scarce in Utah, and a vast and complicated system to manage water quantity, involving ditches, drains, canals and dikes, is used to distribute surface and pumped groundwater to and from irrigated agricultural users, historical and contemporary industrial sites, and ultimately to GSL wetlands (CH2MHill, 2012). Most efforts to quantify (or characterize) disturbance or stressor gradients for wetlands rely on landscape-scale measurements (e.g. cover of various land use classes, road density), or build on some form of best professional judgment to classify wetland stress/disturbance. By contrast, site-scale effects derived from distinct water sources (with distinct types and concentrations of point and non-point source pollutants) are likely to be particularly important to the more sensitive aquatic portions of GSL wetlands. As such, landscape-scale measurements of stress may fail to capture the response of biological indicators attributable to water quality. DWQ is working with UGS to integrate spatial data on wetland locations (e.g. impounded wetland boundaries) with recently acquired high-resolution digital elevation data and surface water networks to better understand the quantity and quality of water flows to GSL wetlands.

1.5 Framework for Fringe Wetland Assessment

This project involved the targeted selection and sampling of fringe wetlands associated with Great Salt Lake. Field work was performed in 2013. Key measures of biological response were plant and aquatic macroinvertebrate community composition. Due to the strong hydrologic element of this wetland type, measurements were made along transects perpendicular to flow at three distances (100, 300 and 500 m) from water inflow to the wetland. Water chemistry samples were collected from the main channel (or flowpath) at each distance and analyzed for a variety of conventional water quality parameters, as well as total nutrients and metals. Macroinvertebrate were collected from inundated areas within and adjacent to the main flowpath, for each distance from the inflow (3 composite samples per site). Plant community composition was measured along the six (6) 50 m perpendicular transects, two opposing transects at each distance from the inflow. Samples of wetland soils were collected adjacent to the main flowpath and at the end of each perpendicular transect (9 samples per site), for analysis of nutrient and metal concentrations, though this work remains partially incomplete due to methodological difficulties in the lab. This report summarizes key results from sample collections, and represents a preliminary effort to identify meaningful and responsive metrics of the relative health (i.e. condition) of this wetland class. Continuing work will refine these metrics and identify potential stressor-response patterns protective of both fringe wetlands and associated downstream uses. DWQ's goal is to identify appropriate biological and ecological characteristics that can be used to refine (or establish) numeric criteria and develop assessment methods for narrative standards that are appropriately protective to people and wetland biota. Once established, DWQ can assess the chemical and physical conditions that are most strongly associated with healthy versus degraded wetlands, which ultimately can be used to define water quality goals that are specific to these ecosystems.

2.0 Methods

2.1 Study Area

The updated National Wetlands Inventory (NWI, 2008) estimated approximately 173,000 hectares (427,000 acres) of wetlands along Great Salt Lake (see Figure 1). These wetlands serve as vital habitat for millions of migratory shorebirds, waterfowl, and other wildlife. In addition, these wetlands provide essential ecosystem services, including moderation of surface water and groundwater flows, and removal of nutrients and other pollutants. There continues to be an essential need to maintain the health and extent of these ecologically critical wetlands, especially in the face of severe and persistent threats from:

- population growth (the majority of Utah's citizens reside within the GSL watershed)
- industrial and urban development
- excessive surface water and groundwater withdrawal
- establishment and dominance of invasive species
- high rates of nutrient loading (Millennium Ecosystem Assessment, 2005; Dahl, 2006).

Protecting and maintaining the health of these ecosystems requires scientifically defensible and quantitative measures of wetland condition.

2.1.1 Geography

This project takes place in fringe wetlands surrounding the Great Salt Lake, Utah, HUC Sub-region 1602. The project area includes portions of Salt Lake, Box Elder, Weber, Davis, and Tooele counties. All fringe wetlands are located above the elevation of GSL and below 4,218 feet above sea level.

2.1.2 Ecological Context

Fringe wetlands occur where freshwater flows over very gently sloping portions of exposed soil or sediments within the GSL basin. Fringe wetlands are commonly found below the outlets from impounded wetlands, wastewater treatment facilities, and other low-gradient surface channels or small streams. Although less common, this wetland type may also be encountered below areas of groundwater discharge, such as springs or seeps.

Most GSL sediments contain substantial quantities of salt, and the salinity of both GSL water and sediments restricts the growth of emergent vegetation. Flow of freshwater over sediments of fringe wetlands can flush

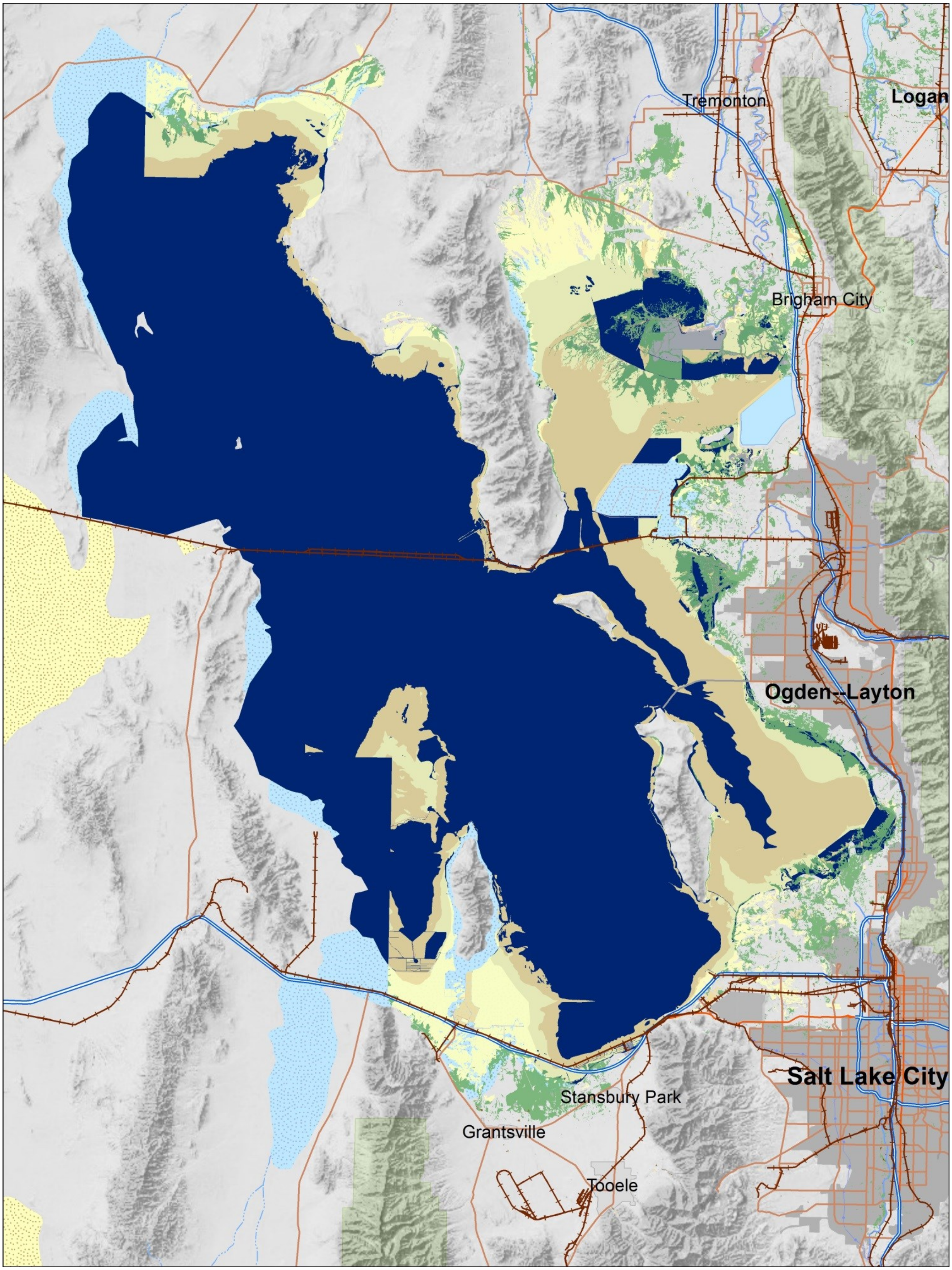

Figure 1. Major wetland classes associated with Great Salt Lake.

enough of the salts out to support various emergent marsh species, including luxurious growth of bulrush (Scirpus spp.), cattail (Typha spp.), and others. Depending on the quantity of water flow, wetland geomorphic features, and lake elevation, fringe wetlands can extend from the border of impounded wetlands to nearly the margin of GSL itself. Longer-term variation in lake elevation (on the order of decades) can "reset" the dominant vegetation of these wetlands by the intrusion of highly saline lake water into the wetland during high-water years. Plants appear to rapidly recolonize fringe wetland areas once lake levels decline and fresh surface water flows or precipitation reduce soil salt content below some, currently unknown, threshold. Many fringe wetlands contain a variety of plant species with variable sensitivity to salt stress and wide gradients in soil and water salinity.

The principal source of water to fringe wetlands is from surface water delivered via extensive networks of impounded wetland outfalls, canals, ditches, and streams. The relative importance of terrestrial vs. aquatic features within these wetlands can change markedly from year to year and across the growing season.

Three important measurement parameters of fringe wetland assessment are plant and macroinvertebrate community composition, including the cover of native and exotic vegetation; water chemistry; and soil chemistry, including analyses of salinity, nutrients, and metals. Water depth appears to exert a strong influence of these parameters, above and beyond any potential effects of water quality, per se. As such, specific efforts were made during site reconnaissance to identify the dominant flow pathways within each wetland where water depths are adequate for sampling. Sampling locations within a given site were at least 50 m from an adjacent dike or shoreline and roughly 100, 300, and 500 m from any water source. These sampling restrictions allowed the field crew to collect data from central portions of the wetland along the major flow pathway, where water chemistry is expected to be most representative of ambient hydrologic conditions.

2.1.1 Land Cover

Fringe wetlands surrounding GSL encompass approximately 121,000 hectares (300,000 acres) and are not typically managed actively by State and Federal agencies for waterfowl habitat. Three main basins contribute the vast majority of surface water to GSL (Arnow, 1984), the Bear River, Weber/Ogden Rivers, and the Jordan River. Menuz et al. (2014) summarized some baseline land cover characteristics of these basins (see Table 1 below) in a recent report on the condition of GSL emergent wetlands.

Table 1. Land cover of major drainage basins contributing to GSL and associated wetlands

Drainage Basin	Area (km^2)	% Open Water	% Wetland	% Woody	% Grazable	% Cultivated	% Developed
Bear	19,463	2.5	3.2	67.6	15.7	8.7	2.3
Jordan	9195	5.0	1.8	67.9	10.7	2.7	11.9
Weber	6436	2.5	2.5	78.3	7.7	1.6	7.2

Adapted from Menuz et al. (2014).

2.2 Site Selection

Sites were selected from GSL fringe wetlands having a defined freshwater source flowing across the site. Because this is a preliminary survey, a targeted selection of high- and low-quality wetlands was used as a first step to compare the ability of various metrics to discern good vs. poor condition (i.e. responsiveness). In an effort to account for a wide range of fringe wetland characteristics, the following categories were developed as part of a desktop evaluation of study sites to clarify potential sources of among-site variation: Historical Sampling Sites, Upstream Water Source, Watershed, and Morphology. A goal of this effort is to identify and characterize potential covariates that may influence wetland condition. Table 2 includes a list of the 20 potential sampling sites and their distribution among these categories. Figure 2 illustrates the approximate location for each of these potential sampling sites.

2.2.1 Historical Sampling Sites

Several fringe wetlands sites were examined in the initial 2004–2006 studies completed by DWQ (CH2M HILL, 2005 and 2006; Miller and Hoven, 2007). Including these sites allowed for an evaluation of how sites have changed over time, and may provide some insight into year-to-year variability. These sites are located at Public Shooting Grounds Waterfowl Management Area, Kays Creek, Central Davis Sewer District's outfall, North Davis Sewer District's outfall, and Farmington Bay Waterfowl Management Area (see Table 2).

Figure 2. Map of proposed fringe wetland sites

2.2.2 Upstream Water Source

This category attempts to account for potential differences in upstream water quality as influenced by distinct types of water sources, as well as hydrologic characteristics of each site. The different upstream water sources include (1) wastewater treatment plants (a point source), (2) creek/irrigation return flow (a nonpoint source in terms of potential contaminants but contributing to the wetland as a point source), (3) groundwater source, and (4) an impoundment (water from point and nonpoint sources has been detained/integrated prior to entering the fringe wetland).

2.2.3 Watershed

This category describes the main hydrologic units (HUC-8 subbasins) providing inflow to these wetlands. The subbasins contribute to distinct bays within GSL that vary in lake salinity. Depending on where the fringe site is located, it could be influenced by GSL waters with a wide range of salinity. These locations include (1) Gilbert Bay, (2) Farmington Bay, and (3) Bear River Bay.

2.2.4 Geomorphology

This category characterizes the influence of local geography on the geomorphology of fringe wetland, including how water enters and flows across the wetland. This category is subdivided into the following: (1) converging site (a dike or pond distributes water over wide area, water flows across mudflat and converges to single channel), (2) diverging site (water starts at a point source, typically a single channel and braids/spreads across mudflat), and (3) groundwater source.

Table 2. Proposed Fringe Wetland Sites

Site ID *	Site Name	Historic Site	Water Source	Location	Morphology	Previously Sampled?
PSGWMA-WLO	PSG – Widgeon Lake Outfall	Yes	Impoundment	Bear River Bay	Diffuse	No
PSGWMA-HLO	PSG – Hull Lake Outfall	No	Impoundment	Bear River Bay	Point Source	No
PROM-01	Promontory Range Springs – 01	No	Groundwater	Bear River Bay	Groundwater	Yes
PROM-02	Promontory Range Springs – 02	No	Groundwater	Bear River Bay	Groundwater	No
Bear-U2D	BRMBR – Unit 2D Outfall	No	Impoundment	Bear River Bay	Diffuse	Yes
BRMBR-U3E	BRMBR – Unit 3E Outfall	No	Impoundment	Bear River Bay	Diffuse	No
HCWMA-BPDR	Harold Crane WMA Bypass Drain	No	Channel	Bear River Bay	Point source	No
HC-East	Harold Crane WMA Off East Pond	No	Impoundment	Bear River Bay	Diffuse	Yes
OBWMA-U1	Ogden Bay WMA Unit 1 Outlet	No	Impoundment	Gilbert Bay	Diffuse	No
OBWMA-WR	Ogden Bay WMA Weber R. Outfall	No	Channel	Gilbert Bay	Point Source	No
HSWMA-NUO	HSWMA North Unit Outlet	No	Impoundment	Gilbert Bay	Point Source	No
HSWMA-SO	HSWMA South Outlet	No	Impoundment	Gilbert Bay	Point Source	No
NDSD	North Davis Sewer District	Yes	UPDES	Farmington Bay	Point source	Yes
TNC-KC	The Nature Conservancy Kays Creek	Yes	Channel	Farmington Bay	Point source	Yes
CDSD	Central Davis Sewer District	Yes	UPDES	Farmington Bay	Point source	Yes [2]*
FBWMA-U1	FBWMA - Unit 1 Outlet	Yes	Impoundment	Farmington Bay	Point source	No
FBWMA-TRPN	FBWMA - Turpin Unit Outlet	Yes	Impoundment	Farmington Bay	Point source	No
FB-SERP	FBWMA - Unit 2 Foremarsh	No	Impoundment	Farmington Bay	Diffuse	Yes
NWOD	NW Oil Drain Outfall	No	Channel	Farmington Bay	Point source	No
ADCO	Ambassador Duck Club Outfall	No	Impoundment	Farmington Bay	Point source	Yes
GOGGDR	Goggin Drain Outfall	No	Channel	Gilbert Bay	Point source	Yes

NOTES: * Two sites were sampled at Central Davis SD. UPDES = Utah Pollutant Discharge Elimination System; PSG = Public Shooting Grounds Waterfowl Management Area; BRMBR = Bear River Migratory Bird Refuge (USFWS); FBWMA = Farmington Bay Waterfowl Management Area; HSWMA = Howard Slough Waterfowl Management Area;

2.2.5 Evaluation of Potential Sampling Sites

The sampling period for this project was July through August, 2013. DWQ evaluated potential sampling sites to confirm selection criteria were met. DWQ's objective was to sample 15 sites in 2013. Criteria to evaluate potential sampling sites include the following:

- Target/Nontarget: *Does the site represent a fringe wetland (> 2 hectares or 5 acres) that is adjacent to GSL and receives freshwater inflow?*
- Permission/Access: *Has explicit permission to access the site been obtained from the landowner?*
- Sampleable: *Can site be sampled during the sampling index period?*
- Representation: *If there is an adequate number of available sites, do the available sites provide an adequate representation for each of the categories listed in Table 2?*

2.3 Field Methods

Each wetland was sampled using a frame as shown in Figure 3 and Figure 4. This sampling frame is designed to allow comparison among fringe wetland sites at a similar scale; therefore, the size and length of transects have been standardized (i.e., 50 m to each side of main flow path). The beginning of the sampling frame (i.e., 0 m distance) is the point where: the open channel penetrates the upland and enters the lakeshore; the end of pipe or the weir that is contributing flow to the wetland; the downstream edge of the dike that has multiple weirs contributing flow; or the groundwater discharges from a spring, located below the transition from upland to lakeshore. If the end of pipe, weir, or groundwater spring is located upstream of the transition from upland to lakeshore, then the beginning of the sampling frame should be located where the resulting flow penetrates the transition from upland to lakeshore.

The fringe wetland class, as defined in this document, contains a wide range of both aquatic and terrestrial features. As such, the sampling layout for this preliminary survey will include measurements of both open water and emergent components of this ecosystem type. The open water, or aquatic, elements of the sampling layout are based on identifying the predominant flow path based on desktop-based geographic information system (GIS) reconnaissance of each site.

Since these wetlands can range in size from approximately 10 to over 1,500 hectares, initial aquatic environmental data collections occurred at three locations representing 10 percent, 50 percent, and 90 percent of the flow path length. However, due to the size of some of the wetland sites, and great difficulty traversing such distances through dense emergent marsh (primarily stands of *Phragmites australis*), flow path lengths were capped at 500 m in this project). As such, transects were placed 100, 300, and 500 m from where surface water enters the wetland. Water chemistry, sediment chemistry, and benthic macroinvertebrate samples were collected at each of these locations, as described below.

The emergent, or terrestrial, elements of the sampling layout were based on two 50 m transects oriented perpendicular to the flow line at 100, 300, and 500 m from the water inflow. Vegetation cover, including emergent and floating aquatic plants as well as algal mats, was estimated visually along a 1 m-wide belt for each transect. Vegetation transects were broken up into 10- or 20 m segments during sampling due to the dense nature of marsh vegetation within this wetland type. At the terminus of each transect, samples were collected for sediment (soil) chemistry and benthic macroinvertebrates. Supplemental data was collected along each transect, including changes in the thickness of organic soil vs. mineral horizons, depth of inundation, and presence of salt crusts.

In general, sampling followed a two-tiered approach, with a focus on both the aquatic and the terrestrial features of this wetland class. Sediment (soil) and macroinvertebrate sampling methods were standardized to allow for comparison of metrics within and across wetlands.

This project will collect data to support three primary sets of indicators (or attributes):

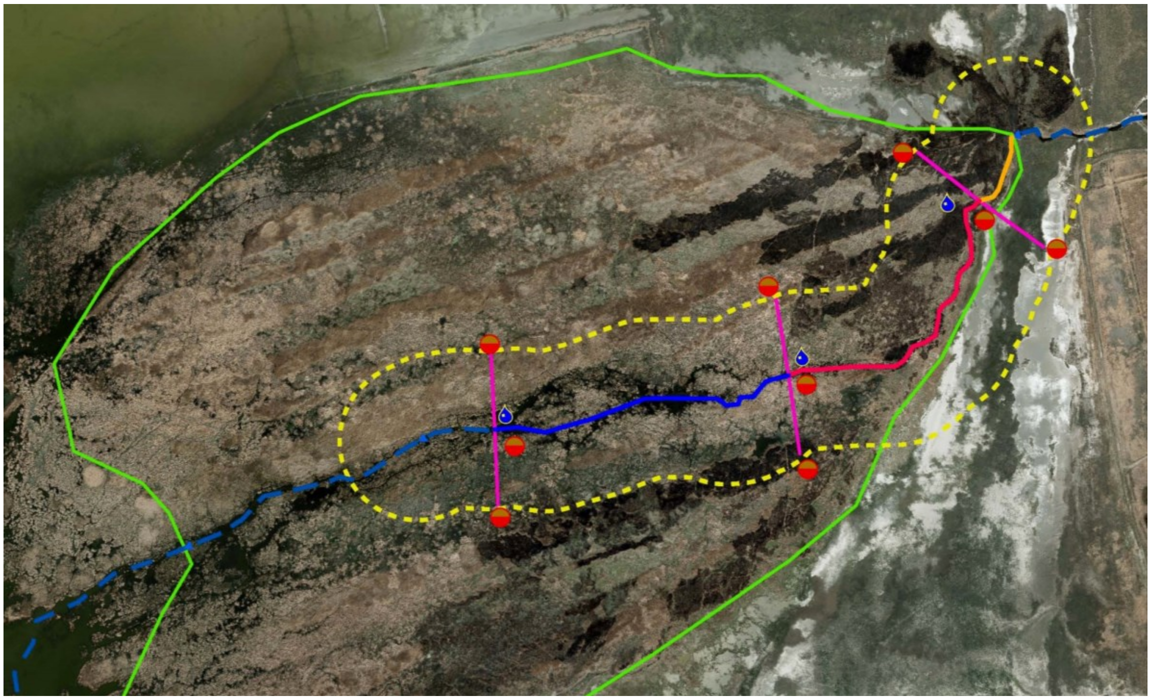

Figure 3. Sample collection frame for fringe wetlands.

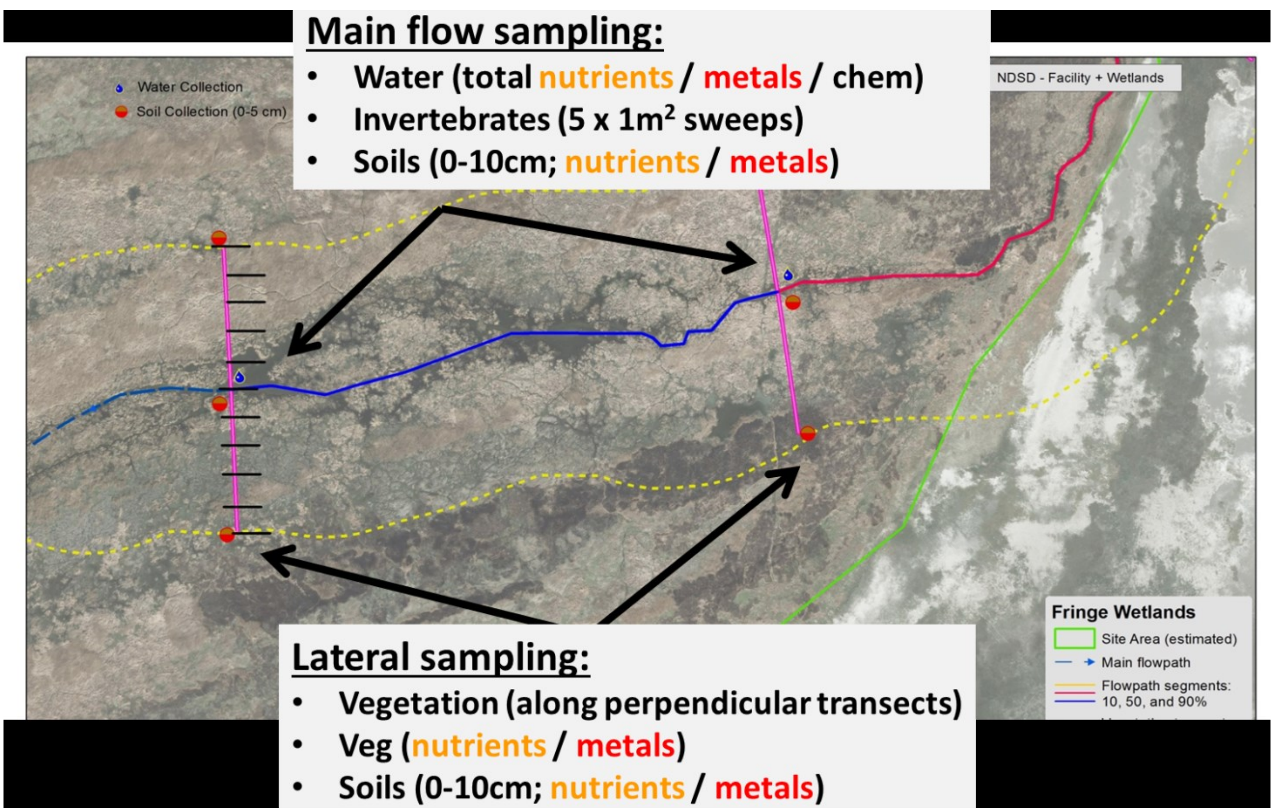

Figure 4. Location of water, invertebrate, soil, and vegetation sample collection within the sample frame.

Vegetation composition and cover observations were collected to characterize the aboveground attributes of the wetlands, which will enable DWQ to define the physical structure of the habitats and will help determine if exotic or invasive species are a significant aspect of each individual wetland.

Benthic macroinvertebrate community composition observations were collected to help characterize the importance of different feeding groups and functional classes in the processing of organic materials in the wetlands.

Water chemistry (nutrients, major ions, and metals) data were collected to characterize the basic constituents available as building blocks for vegetation, macroinvertebrates, and other biological processes. Metal data were used to determine if any potentially toxic conditions were present in the wetlands.

Supplemental indicators include the following:

Sediment extractable nutrients and metals data were collected to help determine if any historical inputs to the wetlands may have deposited nutrients, such as P, or toxic contaminants, such as Hg, that may continue to affect the condition of the wetlands.

Leaf CNP concentrations and $\delta 15N$ isotope ratios of dominant emergent plant species were collected to assess the potential sources of nutrients for plant growth in the wetlands.

These parameters were measured at all sites. A brief description of each measured parameter is found in Table 3.

2.3.1 Environmental Sampling – Water Chemistry

Sampling of water chemistry parameters involves two separate activities, as shown in Table 3. Field parameters were measured using a multi-parameter probe (Hydrolab or similar). This is typically one of the first activities performed during a site visit. Procedures for (daily) calibration and use of the multi-parameter probe are provided in SOPs on DWQ's Wetland Program '*Monitoring and Assessment*' web page (Link)[1]. This project used the temperature, specific conductance, pH, and DO probes. Multi-parameter probe data was recorded on field sheets once the results had been verified as acceptable by the field crew and stored on the instrument; field sheets also included any notes about site conditions observed during the measurement.

Field collection of water samples for chemical analysis is the second sampling component. This was also typically one of the first activities performed during a site visit. Specific procedures for collection of water grab samples are described in the SOP (Link). Several volumes of surface water were collected for six different types of analysis. Five bottles were filled for Total Nutrients, General Chemistry, Total Metals, Sulfide, and BOD5. One or more "transfer bottles" were filled and filtered for Chlorophyll-α analysis (Link).

Both multi-parameter probes measurements and field water samples (bottles) were collected at 100, 300, and 500 m along each flow path segment.

2.3.2 Environmental Sampling – Vegetation

Emergent vegetation and ground cover was sampled by visual estimation of aerial cover within a 1-m band along each perpendicular transect at each distance from the inflow to the wetland. Each transect was broken up into 10- or 20 m segments to facilitate species identification and cover measurements in thick marsh vegetation. These data, along with other pertinent observations, such as cover of algal mats or evidence of soil disturbance, were recorded on a field sheet (Link).

---

[1] SOPs and Sampling and Analysis Plans for DWQ's wetland assessment work can be accessed at: www.deq.utah.gov/Programs Services/programs/water/wetlands/monitoring.htm.

Table 3. Measured Parameters

Description		Field Method*	Details
Vegetation		Visual Observation	1 m wide by 100 m belt-transects perpendicular to main flow path at 10%, 50%, and 90% of path length (up to 500 m); total of three transects per site Vegetation species composition and % cover Cover of Filamentous Algae and Floating Aquatic Vegetation *** No samples were collected, visual observation only*
		Leaf Harvest	Five leaves from dominant plant species at each sampling location; sample mature leaf (fully expanded leaf 1-3 nodes below the top of plant, or the top 30 centimeters of culm (for Schoenoplectus spp.). *** One gallon-size zip bag ** Sent to USU Isotope Lab*
Benthic Macroinvertebrates		Sample Collection using Stovepipe	Five stovepipe collections within dominant flow path, and outside end of each 100 m perpendicular transect (transects composited per perpendicular transect at 10%, 50%, and 90%) *** Two wide-mouth polyethylene quart jars at each sample location ** Sent to Gray Lab*
Water Chemistry	Field Parameters	Multi-Parameter Probe	Temperature, Specific Conductance, pH, Dissolved Oxygen
Water Chemistry	General Chemistry	Grab Sample Collection	Alkalinity, Total Suspended Solids, Total Volatile Solids, Total Dissolved Solids, Sulfate (SO4=), Hardness *** One 1000 mL bottle ** Sent to State Water Lab*
Water Chemistry	Total (unfiltered) Nutrients	Grab Sample Collection	NH4+, NO3-/NO2-, Total Kjeldahl Nitrogen (TKN), Total P, DOC *** One 500 mL bottle with H2SO4 preservative ** Sent to State Water Lab*
Water Chemistry	Total (unfiltered) Metals	Grab Sample Collection	Aluminum, Arsenic, Barium, Cadmium, Cobalt, Copper, Iron, Mercury, Manganese, Nickel, Lead, Selenium, Zinc *** One 250 mL bottle, preserved with HNO3 ** Sent to State Water Lab*
Water Chemistry	Sulfide	Grab Sample Collection	Hydrogen sulfide as total sulfide *** One 120 mL bottle with ZnoAc and NaOH preservative ** Sent to State Water Lab*
Water Chemistry	Chlorophyll-a	Grab Sample Collection and Field Filtering	0.7-µm filter residue *Sent to State Water Lab*
Sediments	Extractable nutrients	Sample Collection using a Corer	Separate 0-10 cm cores at endpoints and center of vegetation transects (Nutrient Extracts: NH4, NO3/NO2, PO4); Total N, Total P and Organic C *** Stored in separate 1-gallon zip bags ** Sent to USU Stable Isotope Lab*
Sediments	Acid-soluble metals	Sample Collection using a Corer	Composite of 0-10 cm cores (collect half of each sediment-nutrient core and composite) for each perpendicular transect Aluminum, Arsenic, Barium, Cadmium, Cobalt, Copper, Iron, Mercury, Manganese, Nickel, Lead, Selenium, and Zinc *** Stored in three separate 1-gallon zip bag** Sent to UU ICP-MS Lab*

2.3.3 Environmental Sampling – Macroinvertebrates

Benthic macroinvertebrates were collected from undisturbed and representative areas within the open water flow path, and inundated areas adjacent to the flow path at 100, 300, and 500 m distances from water inflow. Samples were obtained by a series of three to five ‘D-net’ (500 µm mesh) ‘sweeps’ along a swath approximately 30 cm wide by 100 cm long. In dense vegetation, efforts were made to clear much of the upper portions of aboveground biomass from the area without overly disturbing the surface soil prior to a sweep. Vegetation, detritus, and surface soil materials were commonly included in the sample so that invertebrates adhering to these materials were not discarded; these materials were removed in the laboratory during sample identification and enumeration. Samples were composited for each sampling location (n=3 per site). Procedures are described in the SOP (Link).

2.3.1 Environmental Sampling – Soils

Sediment available nutrients and total metals were sampled from an undisturbed area within the open water flow path and at the end of each vegetation transect for all three sample locations (100, 300, and 500 m distances). Briefly, the goal was to collect the top 10 centimeters of loose sediment (or mucky soil) from 5-cm diameter cores. The 0- to 10-centimeter core was split longitudinally in the field, using a soil spatula, and each half of the core placed in separate 1-gallon sample bags. One-half of the core was placed in a labeled bag for nutrients; the other half of the core was placed in another labeled bag for acid-soluble metals. Nine samples were collected per site (3 locations per transect distance x 3 distances) for both nutrient and metals samples (Link).

2.4 Laboratory Methods

All chemical analyses were performed in accordance with standard laboratory methods by the contracted laboratories. Specific details for each method and laboratory are located in the project SAP (DWQ, 2013).

2.5 Data Quality Objectives

Data quality objectives are qualitative and quantitative statements derived from systematic planning that clarify the study objective, determine the most appropriate types of data to collect, determine the most appropriate conditions from which to collect data, and specify the level of uncertainty allowed in the collected monitoring data while still meeting project objectives (EPA, 2006). Project specific information is summarized in Table 4 below.

Table 4. Data Quality Objectives

Step	DQOs for 2013 Great Salt Lake Fringe Wetland Targeted Survey
Problem Statement	Wetland resource managers and engaged stakeholders had previously observed algal mats within GSL wetlands and expressed concern that this could be an indicator of poor wetland health resulting from high N and P loading from wastewater treatment facilities, possibly impacting the food sources of waterfowl and shorebirds using these areas. It was suspected that wetlands with high nutrient loads may not be supporting their beneficial use of waterfowl habitat and necessary food chain. In response, DWQ initiated the development of a framework to assess the relative condition of impounded and fringe wetlands of GSL. The assessment framework for impounded wetlands has been refined and now awaits further testing. This project represents the initial data collection effort for fringe wetlands to inform a preliminary MMI, based on wetland condition / integrity.
Goal of Study / Decision Statements	*Key Question[s]* Q0: What key variables define the function, characteristics, and condition of GSL fringe wetlands? Q1: What stressors are impacting the condition of GSL's fringe wetlands? Q2: What metrics are most useful for evaluating wetland condition and stress with respect to beneficial use classes? *Potential Outcomes* 1: Information is adequate to answer the key questions, resulting in a preliminary MMI for fringe wetlands to be shared with wetland managers and stakeholders, and subsequently validated using a probabilistic survey. 2: Information is inadequate to develop robust metrics of relative condition of fringe wetlands. DWQ will identify potential confounding factors, develop appropriate sampling and analytical methods, revise the sampling plan, and complete reporting as above.
Inputs to Decision	The following information was collected: Field sampling, included collection of water chemistry and biota samples, was conducted one time during the 2013 growing season (midsummer) at 10 selected sites adjacent to GSL. *Water chemistry parameters*: Total nutrients, total metals, chlorophyll a, general chemistry (major ions, suspended solids), and field measures (DO, temp, pH, salinity) using appropriate and documented methods. *Benthic macroinvertebrates*: Species composition of benthic macroinvertebrate communities using appropriate and documented methods. *Field measures of vegetation and surface mat* cover were collected using appropriate & documented methods. *Sediment metals and nutrient availability*: Total (digested) metals and exchangeable nutrient concentrations using appropriate & documented methods. *Field observations of stressors*, including soil and vegetation disturbance, altered hydrology, over grazing, and the establishment and dominance of invasive plant species. Supplemental Indicators may be collected. These include: Leaf C, N, and P concentration, and $\delta^{15}N$ and $\delta^{13}C$ isotope ratios from dominant emergent plants along transect endpoints and open water sampling locations. This information is described in Section 2.3and Table 3.

Step	DQOs for 2013 Great Salt Lake Fringe Wetland Targeted Survey
Study Boundaries	The study area for this project includes fringe wetlands within Farmington Bay, Ogden Bay, Bear River Bay, and Gilbert Bay portions of Great Salt Lake. Spatial data identifying fringe wetlands is derived from reclassified National Wetland Inventory data and other sources as available. Sampling sites were field-checked to ensure that they: *Represent the sample target*—Fringe wetlands associated with and adjacent to the GSL *Are accessible*—DWQ has received permission to visit wetlands on private property Weather is a major constraint for all sampling and monitoring activities because storms can limit access to field sites and the ability to safely conduct sampling and measurement activities at the study area. GSL levels and private property access may be a constraint and affect sampling locations. Ownership information and permission was obtained as early in the study as possible.
Decision Rules	If information is adequate to answer the key questions, then DWQ will present results and recommendations in a final report. If information is inadequate to answer the key questions; DWQ will identify potential confounding factors, develop appropriate sampling and analytical methods, revise the sampling plan, and complete reporting as above.
Acceptance Criteria	PARCC elements for data *Precision*—Because of the difficulty obtaining sufficient sampling sites, field replicates were not collected in 2013. *Accuracy*—Special efforts were made to minimize contamination of water chemistry samples through proper collection of field samples and use of appropriate laboratories for analysis. Field surveys were performed by a monitoring crew trained in each method. Few species of vegetation occur within the project area and are generally easily identified, but questionable specimens were collected and returned to the office for further identification. Taxonomic identification of macroinvertebrates was performed by Dr. Larry Gray (Utah Valley University). *Representativeness*—The sampling locations have been selected based on a review of aerial photos, and sites were chosen due to their landscape scale characteristics. Sites were chosen to encompass potentially unique characteristics of different conditions, such as water source, potential salinity impacts, and morphology. Inventory methods were designed to collect data at a scale most descriptive of GSL wetlands (~ 50 hectares). Site photos and field notes were collected at each site to describe any unusual conditions that may occur. *Completeness*—To ensure the sampling goal of 100 percent completeness at the end of the season, we will use field reconnaissance to verify that sites have the proper hydrologic conditions to support fringe wetlands. *Comparability*—All field sampling and analytical procedures were completed following both previously tested and newly developed SOPs for each metric and were performed by the same field crew throughout the sampling season. Measurement quality objectives for chemical measurements are specified in the SAP (DWQ, 2014). DWQ QAPP specifies the minimum QA/QC objectives for sample measurement.
Sampling Plan and Design	The baseline sampling program includes the following: Collection and analysis of water, macroinvertebrates, and surface sediments for chemical, physical, and taxonomic attributes, as appropriate Field observations of vegetation and algal mat cover Data were used to estimate baseline conditions of fringe wetlands associated with GSL. Forthcoming analyses will use data to construct MMIs for key indicators, such as Water Chemistry, Benthic Macroinvertebrates, Vegetation, and Sediment Chemistry, following reasonable and convincing linkage to beneficial use of these wetlands, via examination of relationships among wetland physical, chemical, and biological condition; other indicators may be developed as appropriate.

3.0 Data Analysis

The current number of sample sites is small and we are in the early stages of metric identification and calibration steps for this wetland class which will support only relatively simple analytical approaches. Information on site characteristics was aggregated for each site. Taxa lists were developed for plant and macroinvertebrate communities and organized into preliminary databases to support comparisons with local and regional literature and expertise. The structure of the plant and macroinvertebrate databases is still being developed, largely in collaboration with others working on other GSL wetland types, but currently includes information on plant wetland indicator status (hydrophytic vegetation), physiognomy and 'C-values' (coefficients of conservatism; see Menuz et al. 2014). The macroinvertebrate taxa database includes taxonomic classification, taxon codes and lowest taxonomic units (LTUs), feeding group and common-language descriptive class of organism (e.g. diving beetle, biting midge, and flatworms). These databases are being supplemented with information from other wetland classes as well as historical data collections.

Plant community composition data were derived from the 1 x 10-m quadrats (or segments of belt transects); these data have been summarized (averaged) by transect (n=6 per site) for analyses. Both total and relative cover of plant taxa were examined for metric development. An initial set of indicators includes the relative dominance of invasive species, plant species richness, and the potential identification of species groups that commonly co-occur across the wetlands (e.g. nitrophilous species, xeric invaders).

Aquatic macroinvertebrate data were derived from composite samples collected within inundated microsites at 100, 300, and 500 m from surface water inflow to the site (n = 3 per site). Initial indicators include taxa richness, Simpsons diversity (distance) measure, and the potential identification of taxa-groups that co-occur across wetlands.

Water chemistry samples were collected from the main flowpath within the wetland at 100, 300, and 500 m from surface water inflow to the site (n = 3 per site). These data were compared to available benchmarks from regional freshwater systems.

Soils data were summarized by transect distance (n = 3 per site) for general analysis. Similar to water chemistry, the distribution of these data were compared to soil/sediment benchmarks, as available.

Given the limited number of sites sampled in 2013, only basic statistical analyses were performed to minimize the impact of potentially spurious associations. Generally, data evaluation was focused on how data varied among sample units, both within and across sites, and whether ecologically reasonable patterns were discernible among variables within an attribute class (i.e. among plant, water chemistry, or macroinvertebrate variables), using ordination. As such, the number of pairwise correlation (or similar) analyses was kept to a minimum, in an effort to avoid a large number of likely spurious relationships as well as building on previous work that outlined some fundamental characteristics of this wetland class (see CH2MHill, 2005, CH2MHill, 2006). Distinct water sources to fringe wetlands were considered, *a priori*, a potentially important driver of site-scale effects on biological communities, and was overlaid on ordination plots. In addition, comparisons among attribute types (e.g. invertebrates vs. plants) were transformed to a common scale (i.e. plant data was aggregated to site x distance scales (n=3 per site)) prior to analysis.

Most data manipulation was performed using Microsoft Access and Excel 2010. Data summaries, graphing and univariate statistical analyses were conducted in R 3.0.2 (R Core Team, 2014) and R-Studio (version 0.98.1062; www.rstudio.com/), using various widely available packages. Ordination, using non-metric multidimensional scaling (NMDS) was conducted using PC-ORD 6.0 (McCune and Medford, 2011).

4.0 Results

4.1 Site Characteristics

The initial set of 21 sites (Table 2) was evaluated by desktop and field reconnaissance, as described in Section 2.3. Only 9 areas were deemed suitable for sampling in 2013 based on wetland hydrology and site access. For the 12 areas that were not suitable, 10 were much drier than expected, one area was wetter, and one area could not be accessed. Areas of fringe wetlands with lower water levels were due to efforts by state land management agencies to reclaim extensive former marsh areas invaded by *Phragmites australis* (common reed), an aggressive and noxious weed. Current management techniques include a multi-year drawdown via reduced inflows, combined with periods of intense grazing after herbicide application to inhibit regrowth. Another fringe wetland area, adjacent to a *Phragmites* control area, had water levels 4 to 6 feet (1.2 to 1.8 m) higher than expected and was deemed too dangerous to sample. The higher water level was a consequence of restricted outflow to over 20 culverts along 5 miles of impounded wetland dikes, such that the outflow to the remaining open culvert was increased by over 100 ft^3/sec (estimated) in 2013. Finally, one area could not be sampled due to lack of permission to cross private lands.

One additional site was added to a wetland area below the Central Davis Sewer District's wastewater treatment plant (WWTP), because this extensive wetland area had two significant flowpaths: a main channel through the center of the marsh, and a second channel that seemed to flow between the marsh and an adjacent wet meadow.

We sampled fringe wetland sites with four distinct water sources, from three GSL bays, three types of wetland morphology, and four of six historical sites (Table 5).

Table 5. Wetland Site Factors

Water Source	Location	Morphology	Historic Site
Impoundment (4)	Bear River Bay (3)	Diffuse (3)	Yes (4)
Groundwater (1)	Gilbert Bay (1)	Groundwater (1)	No (6)
Channel (2)	Farmington Bay (6)	Point Source (6)	
UPDES (3)			

Site characteristics are shown in Table 6. Wetland area was estimated from available aerial imagery (Utah AGRC; {Link}). While fringe wetland area is expected to be proportional to water supply, multiple flowpaths within larger wetland complexes and substantial year to year variation in water supply affect measurement accuracy and precision. As such, the areas of fringe marsh shown in Table 6 are provided to give a sense of the relative size of the wetland areas. For sites sampled in 2013, marsh area ranged from 36.7 ac (14.9 ha) to over 780 ac (316.3 ha) across sites.

Table 6. Summary of Wetland Area and Vegetation Characteristics

Site Name	Monitoring Location ID	Wetland Area	Emergent Vegetation cover	Plant Species Richness	Invasive Species Relative Cover	Vegetation Height	Standing water	Water depth
ADCO	5972380	104.9 / 42.5	67.6	9	73.9	1.9	82.0	10.5
Bear-U2D	5972250	781.7 / 316.3	56.0	15	80.9	1.5	8.8	7.3
CDSD-01	5972340	298.8 / 120.9	95.0	3	98.6	2.1	40.9	12.4
CDSD-02	5972350	51.8 / 21.0	86.9	24	24.1	1.7	53.2	7.2
FB-SERP	5972360	470.3 / 190.3	49.9	13	3.5	1.1	66.4	24.5
GOGGDR	5972390	214.8 / 86.9	50.8	16	79.1	1.1	< 1	0
HC-East	5972280	114.4 / 46.3	88.3	14	64.1	2.5	70.4	6.7
NDSD	5972200	195.2 / 79.0	82.9	22	51.5	1.8	44.0	22.0
PROM-01	5972300	36.7 / 14.9	51.4	17	0.4	0.5	22.9	2.6
TNC-KC	5972330	97.2 / 39.3	82.5	19	1.9	2.1	78.3	15.1
(Units)		ac / ha	%		%	m	%	cm

All sampled sites were well vegetated, with total cover of emergent vegetation ranging from 50% (patchy areas of marsh adjacent to a channel) to over 90%, consistent with a mix of saltgrass meadow and emergent marsh communities encountered throughout the area. We also observed a wide range of inundation among sites, from < 1% within the channelized delta of the Goggin Drain to over 80% within marshes below Ambassador Duck Club and Kay's Creek.

A notable feature of this wetland class is the variety of aquatic vs. terrestrial features among sites. Building on regulatory assessment methods for streams, lakes and shallow ponds, the aquatic features of fringe wetlands may be considered the most sensitive to point-source discharge-related impacts. This sensitivity is likely due to the greater contact time between aquatic organisms and the receiving waters, relative to organisms inhabiting more terrestrial habitats (e.g. aquatic insects or algae vs. terrestrial insects or mosses), as well as the distinct types of organisms that inhabit aquatic versus terrestrial habitats (or microsites) of wetlands. Mean water depths ranged from less than an inch (< 2.6 cm) at Promontory Spring and Goggin Drain to over 20 cm at North Davis SD and Farmington Bay (FB-SERP; see Table 2 and Table 6 for site names), illustrating a wide range in the distribution of aquatic versus terrestrial microsites.

4.2 Biological Response Indicators

Two biological responses of fringe wetlands were examined in this study, based on the composition of emergent vegetation and benthic macroinvertebrate communities. Plant community composition data was analyzed after averaging the five 1 x 10 m plots within each transect (two lateral transects at each distance-segment (100, 300, and 500 meters from the upstream wetland boundary; n=6 per site) for all species observed (see Figure 3). Macroinvertebrate community data were based on composite collections of D-net sweeps in inundated areas located in segments 100, 300, and 500 meters from the upstream wetland boundary (n=3 per site).

4.2.1 Plant Community Composition

A total of 54 plant taxa were observed within the vegetation plots; this includes three additional plant cover elements (mat-forming algae, standing dead vegetation, and unidentified grasses) that were treated as separate plant species. Ten (10) species were removed from the dataset because they occurred in only one plot at one site, or because the species was very rare and data could be combined with another, very similar and co-occurring species (e.g. Epilobium ciliatum and E. palustre). Summary characteristics of the remaining 44 species are shown in Table 7; results are based on mean cover data for each transect (n=6) per site (n=10).

The most common plant species was *Phragmites australis*, based on its frequency of occurrence and mean cover across sites. We suspect that our measurements largely refer to the non-native (and invasive) subspecies rather that the native one, given the high plant density and overall vigor (plant heights over 3 m) of the vegetation in disturbed environments. Distinguishing the native vs. non-native form in the field is difficult and no attempt was made to separate them. *Phragmites* was observed in nearly 75% of all transects and had the highest mean cover of 33.8%. The next 6 species in Table 7 were also common, observed in more than 25% of all transects. *Schoenoplectus americanus*, a common dominant within GSL marsh systems was observed in 47% of transects, while a floating aquatic plant, *Lemna minor,* was observed in 38% of transects. Other species include: *Distichlis spicata,* two species of *Typha*, and *Hordeum jubatum.*

Across sites, the total number of plant species within transects (i.e plant species richness) ranged from 3 to 24 (Table 6). The site with the lowest richness, CDSD01, was dominated by *Phragmites*, *Lemna minor* (duckweed, a floating plant), and dead stems of *Typha* and *Phragmites* (a few areas of live *Typha* spp. were also present, but not observed in transects). By contrast, two sites (NDSD (22 species) and CDSD02 (24 species)), had more than 20 species from marsh and aquatic habitats. Interestingly, the dominant water source of all three sites was treated-effluent from adjacent WWTPs.

Table 7. Characteristics of Observed Plant Species, ranked by relative frequency

Species Name	Species Code *	Rel. Freq. (%) §	Rel. Freq. Rank	Mean Cover (%)	Cover Rank	Indicator † Status	Native? ‡	Plant Group **
Phragmites australis	PHAU	73	1	33.8	1	FACW	N	Gr
Schoenoplectus americanus	SCAM	47	2	14.5	2	OBL	Y	Cyp
Lemna minor	LEMI	38	3	4.6	4	OBL	Y	Aq
Distichlis spicata	DISP	32	4	3.9	6	FAC	Y	Gr
Typha domingensis [1]	TYDO	32	4	4.1	5	OBL	Y	Cyp
Typha latifolia [1]	TYLA	28	6	8	3	OBL	Y	Cyp
Hordeum jubatum	HOJU	25	7	0.7	15	FAC	Y	Gr
Atriplex prostrata [2]	ATHE	23	8	0.5	16	NI	N	F
Polypogon monspeliensis	POMO	23	8	0.41	23	FACW	Y	Gr
Unspecified mat-forming algae [3]	Algae	22	10	3.3	7	OBL	Y	Aq
Salicornia rubra	SARU	22	10	0.9	14	OBL	Y	F
Schoenoplectus maritimus	SCMA	18	12	1.7	8	OBL	Y	Cyp
Stuckenia pectinata	STPE	18	12	0.9	13	OBL	Y	Aq
Sueada calcioformis	SUCA	18	12	1.1	12	FACW	Y	F
Tamarix rammossima	TARA	18	12	1.6	9	FAC	N	SS
Bidens cernua	BICE	13	16	0.3	14	OBL	Y	F
Lactuca serriola	LASE	13	16	< 0.1	38	FACU	N	F
Nasturtium officianale	NAOF	13	16	0.1	30	OBL	Y	Aq
Cardaria draba	CADR	12	19	1.2	11	NI	N	F
Standing dead [4]	DEAD	12	19	1.3	10	NI	Y	Dd
Rumex cripsus	RUCR	12	19	0.1	26	FAC	N	F
Polygonum lapathifolium	POLA	10	22	< 0.1	33	FACW	Y	F
Bassia scoparia	BASC	8	23	0.1	25	FAC	N	SS
Eleocharis palustris	ELPA	8	23	0.1	24	OBL	Y	Cyp
Epilobium ciliatum	EPCI	7	25	< 0.1	40	FACW	Y	F
Lepidium perfoliatum	LEPE	7	25	< 0.1	36	FACU	Y	F
Phalaris arundinaceae	PHAR	7	25	< 0.1	41	OBL	Y	Gr
Bromus tectorum	BRTE	5	28	0.1	28	NI	Y	Gr
Potamogeton crispus	POCR	5	28	< 0.1	37	OBL	N	Aq
Poa palustris	POPA	5	28	0.1	27	FAC	Y	Gr
Polygonum persicaria	POSP	5	28	0.1	29	FACW	Y	F
Ranunculus cymbalaria	RACY	5	28	< 0.1	42	OBL	Y	Aq
Convolvulus arvensis	COAR	3	33	< 0.1	39	NI	N	F
Unidentified grasses	Grass	3	33	0.2	22	NI	Y	Gr
Schoenoplectus acutus	SCAC	3	33	< 0.1	34	OBL	Y	Cyp
Sisymbrium altissimum	SIAL	3	33	< 0.1	43	FACU	N	F
Spergularia marituma	SPEMAR	3	33	0.2	18	FACW	N	F
Alopecurus arundinaceus	ALAR	2	38	< 0.1	32	FAC	Y	Gr
Chenopodium album	CHAL	2	38	0.2	19	FACU	Y	F
Cirsium foliosum	CIFO	2	38	< 0.1	35	NI	Y	F
Solidago canadensis	SOCA	2	38	0.1	31	NI	Y	F
Solanum dulcamarum	SODU	2	38	0.2	20	FAC	Y	F
Thinopyrum intermedium	THIN	2	38	0.2	21	NI	Y	Gr
Veronica anagallis-aquatica	VERANA	2	38	< 0.1	43	OBL	Y	F

Notes: [1] Two *Typha* species (including potential hybrids) are difficult to distinguish in the field; future work will aggregate data by genus until a suitable field key is developed. [2] Species initially listed as A. heterosperma, but subsequent discussion with UGS and USU botanists suggests a complex of A. prostrata, A. micrantha, and possibly the native A. dioca (see Appendix G. in Menuz et al. (2014)) that will require further inspection. [3] Cohesive mats of algae floating within water column or covering inundated soils; cover aggregated as one class until field key can be developed. [4] Standing dead plant stems were measured as if alive, aggregated across species. [*] Species codes are those used in field by lead author, and are not identical to the USDA Plants database or other sources. [§] Total number of transects possible is 60 (6 transects x 10 sites). [†] Status of hydrophytic plant species, based on the US Army Corps of Engineers plant list for the Arid West region. [‡] Plant native status derived from Menuz et al. (2014). [**] Preliminary grouping of plant species based on their occurrence (aquatic species) and growth form (forbs and grasses).

The relative cover of invasive species among sites ranged from < 1 % to over 95% (Table 6). Three sites (PROM-01, TNCKC, and FB-SERP) had low cover of invasives, while six sites were dominated by invasives (relative cover > 50%). The latter sites were typically dominated by *Phragmites*, however, the GOGGDR site (Goggin Drain delta wetland) also had substantial cover of *Tamarix* and *Cardaria* (site averages of 14 and 9% cover, respectively).

Sites dominated by invasive species typically had lower species richness. A scatterplot of species richness against relative cover of invasive species suggests a potential relationship, where species richness declines as relative cover of invasive species increases beyond approximately 20-30% (Figure 5 below). Given the limited dataset, this pattern could be spurious. However, a reasonable mechanism may be that increasing dominance of one species results in competitive exclusion of others in these highly productive wetlands. Three sites do not fit this pattern, and could represent a subset of reference standard sites having little cover of invasive species. Neither species richness nor relative cover of invasives were correlated with total plant cover, suggesting that this pattern is not driven by plant abundance, *per se*. If sites with low cover (< 10%) of invasive plants are considered reference standard sites, the pattern of decreasing species richness with increasing dominance by invasive plants may be a fruitful indicator of wetland condition.

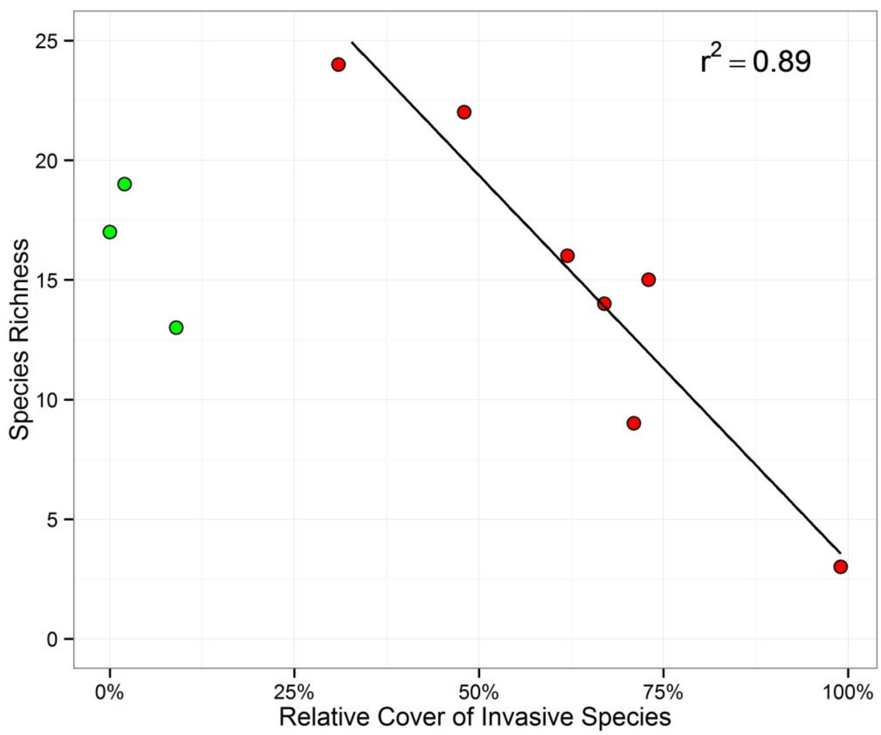

Figure 5. Mean plant species richness vs. relative cover of invasive species, site averages.

4.2.1.1 NMDS Ordination of Plant Community Data

An optimum NMDS solution for plant community composition data contained two axes and a final stress value of 15.1. There was modest evidence for an association between the two NMDS axes and 8 of the 44 plant species (Table 8), and 4 of 8 initial site variables (Table 9). A gradient in plant community composition could be described by the four water source classes (Figure 6), based on NMDS scores. While there was substantial overlap among Impounded Wetland, Channel, and UPDES water sources, plant species scores highlight an apparent moisture gradient from taxa representative of aquatic habitats (algal mats, *Stuckenia*, *Potamogeton crispus*, etc.) in the upper left, to drier-site (and weedy) species (*Bromus tectorum*, *Sisymbrium sp.*, *Atriplex sp.*, *Tamarix*, etc.) in the lower right portions of the figure. Transects characterized by mainly aquatic habitats were most common in fringe wetlands receiving water from shallow impoundments (upper left portion of Figure 6), while drier habitats were most common in areas with channelized flowpaths (lower right). Transects dominated by *Phragmites australis* (upper-middle portion of Figure 6) occurred in wetlands receiving water from impounded wetlands, channels, or UPDES-effluent discharges, and were intermediate along the apparent moisture gradient.

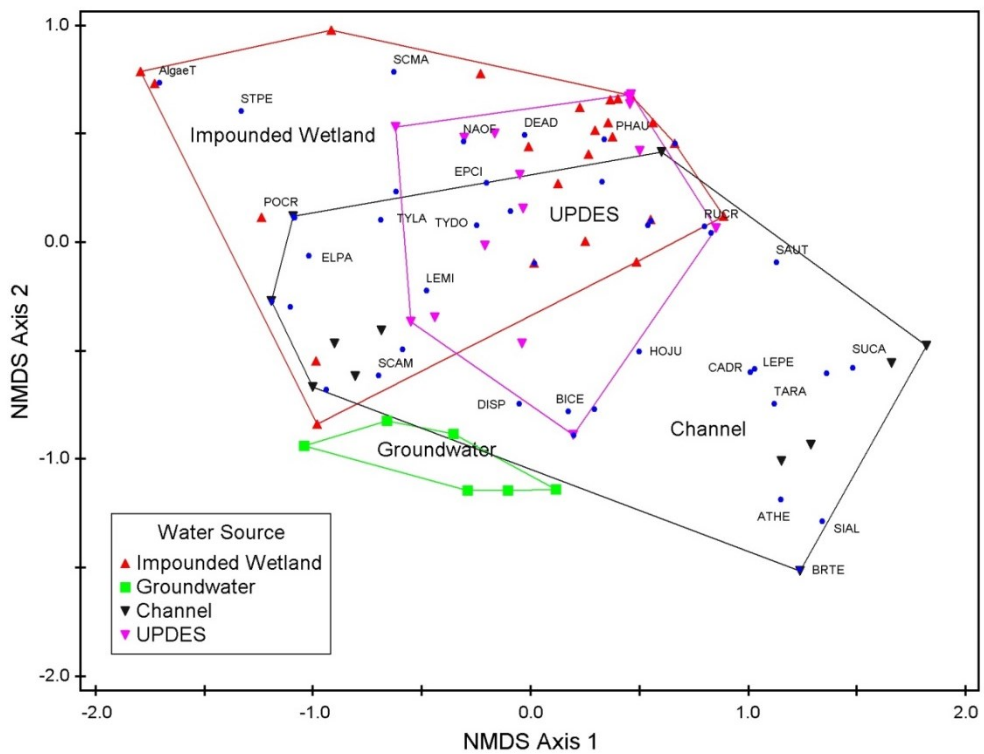

Figure 6. NMDS ordination of plant community data.

Table 8. Potential associations between plant species and Veg-NMDS axis 1 and 2 scores.

Symbol	Species Name	NMDS Axis 1			NMDS Axis 2		
		Pearson (r)	R^2	Kendall's Tau (τ)	Pearson (r)	R^2	Kendall's Tau (τ)
PHAU	*Phragmites australis*	**0.43**	0.19	**0.42**	**0.72**	0.52	**0.60**
SCAM	*Schoenoplectus americanus*	**-0.51**	0.26	**-0.53**	**-0.54**	0.29	**-0.48**
TYLA	*Typha latifolia*	**-0.41**	0.17	**-0.41**			
DISP	*Distichlis spicata*				**-0.45**	0.20	*-0.35*
Algae	Unspecified mat-forming algae	**-0.44**	0.19	*-0.31*			
SUCA	*Sueada calcioformis*	**0.45**	0.21	*0.32*			
STPE	*Stuckenia pectinata*	**-0.46**	0.21	*-0.38*			
SARU	*Salicornia rubra*	**0.42**	0.17	*0.36*			

Strength of associations based on Pearson's (r) and Kendall's Tar (τ) statistics, where correlation scores > 0.4 and < -0.40.

Table 9. Potential associations between environmental site variables and Veg-NMDS axis 1 and 2 scores.

Site Variable	NMDS Axis 1			NMDS Axis 2		
	Pearson (r)	R^2	Kendall's Tau (τ)	Pearson (r)	R^2	Kendall's Tau (τ)
Maximum emergent plant height				**0.44**	0.19	0.30
Cover of standing water	**-0.55**	0.30	**-0.44**			
Mean water depth	**-0.61**	0.37	**-0.51**			
Mean TDS				**-0.45**	0.20	-0.11

Strength of associations based on Pearson's (r) and Kendall's Tar (τ) statistics, where correlation scores > 0.4 and < -0.40.

4.2.2 Wetland Macroinvertebrates

A total of 42 aquatic and two terrestrial macroinvertebrate taxa were identified from samples collected at 29 locations within the 10 fringe wetland sites (Table 10). Taxa abundance data were aggregated by taxon codes provided by Dr. Larry Gray. The relative abundance of 28 taxa were analyzed, after removal of taxa occurring at less than two sites. Six taxa were common, observed in at least eight fringe wetland sites sampled in 2013: three subfamilies of chironomids (non-biting midges), a snail (*Physella* sp.), an amphipod (*Hyalella Azteca*), and a dragonfly (*Aeschna*). With the exception of *Aeschna*, these taxa were also quite abundant where they occurred. The most common taxa, chironomids of subfamily chironominae (Taxon Code 84; see Table 10) was also the most abundant, reaching densities of well over 1000 individuals per sample (composite of three to five x 0.75 m^2 sweeps).

Across sites, the number of distinct taxa (taxa richness, by taxon code) ranged from 1 to 22. For transects, taxa richness ranged from 1 (eight transects) to 16 (two transects) (Table 11). Interestingly, when only one taxa occurred it was always the chironominae subfamily (tribes tanytarsini and chironomini) that was collected.

It is likely that estimates of macroinvertebrate community diversity were underestimated, at least in some sites, due to low invertebrate abundance in some samples (Table 11). As a general rule, at least 200 individuals are preferred for an appropriate evaluation of community composition (King and Richardson, 2002). Of the 29 macroinvertebrate samples collected, 16 samples had fewer than 200 individuals. In addition, four sites had low total macroinvertebrate abundance: Goggin delta (GOGGDR), Bear River Unit 2D (Bear-U2D), Farmington Bay (upper Unit 2; FB-SERP), and Central Davis outfall marsh (#2; CDSD-02) (see Table 11).

Since this analysis is both preliminary and exploratory, all data were examined. While there was no statistical relationship between the abundance and richness of macroinvertebrate samples, no sample with less than 300 individuals had more than 9 taxa, so caution should be applied when interpreting possible community patterns.

4.2.2.1 NMDS Ordination of Macroinvertebrate Community Data

An optimum NMDS solution for macroinvertebrate community composition was obtained after recalculating sample data as relative abundance, and using Jaccard's distance measure. The solution contained three axes and a final stress of 6.0. There was modest evidence for an association between the three NMDS axes and 7 of 28 invertebrate taxa (Table 12) and 7 of 25 site variables (Table 13). While wetlands receiving water from surface water channels and groundwater (springs) were clearly separated by the invertebrate NMDS (Figure 7), there was substantial overlap among invertebrate communities receiving water from impounded wetlands compared to treated effluent (UPDES sites).

Four potential groups of invertebrate taxa for discriminating among sites are broadly apparent from Figure 7. Group 1 includes two snails (*Stagnicola* and *Gyraulus*) and is associated with 3 samples with IWs as the water source. The remaining groups include mixes of distinct taxa. Group 2 is associated with 4 samples from 3 sites having IWs and treated effluent as dominant water sources. Group 2 taxa include a snail (*Physella*), a fly (*Caloparyphus*), a biting midge (Ceratopononinae), and an aquatic beetle (*Tropisternus*), representing scrapers, collector-gatherers and predator feeding groups. Group 3 is associated with 4 samples downstrean of a wastewater treatment plant, and includes an isopod (*Caecidotea*), a fly (*Sepedon*), a diving beetle (*Hydroporus*) and an aquatic beetle (*Cyphon*), representing the collector-gatherer, predators, and scraper feeding groups. Group 4 (14 samples, 5 sites) is associated with two channel-dominated sites (Goggin drain and Kay's creek) and some samples with IW and effluent water sources, and is the most taxa-rich group.

Table 10. Macroinvertebrate Taxa collected

Major Group:	Family	Lowest taxonomic Unit	Taxon Code	Feeding [1] Group	Rel. Freq. samples [2]	Rel. Freq. sites
Aquatic Insects: Ephemeroptera	Baetidae	*Callibaetis*	273	GC	14%	20%
:Trichoptera	Phryganeidae	*Phryganea*	prg	OM	3%	10%
:Odonata	Coenagrionidae	*Ischnura*	350	PR	17%	30%
	Coenagrionidae	*Enallagma*	350	PR	7%	20%
	Aeshnidae	*Aeshna*	345	PR	28%	60%
	Libellulidae	*Erythemis*	356	PR	14%	30%
:Hemiptera	Corixidae	*Corisella*	330	PR	21%	40%
	Corixidae	*Hesperocorixa*	330	PR / PH	3%	10%
	Notonectidae	*Notonecta*	335	PR	21%	40%
	Belostomatidae	*Lethocerus*	329	PR	3%	10%
:Diptera	Chironomidae	*Chironomus*	84	GC	59%	70%
	Chironomidae	tribe Tanytarsini	84	GC	31%	50%
	Chironomidae	subfamily Tanypodinae	89	PR	34%	60%
	Chironomidae	subfamily Orthocladiinae	86	GC	28%	60%
	Ceratopogonidae	subfamily Ceratopogoninae	179	PR	10%	20%
	Tipulidae	*Holorusia*	hol	SH	3%	10%
	Sciomyzidae	*Sepedon*	243	PR	7%	20%
	Ephydridae	*Ephydra*	235	GC	10%	20%
	Ephydridae	*Notiphila*	235	GC	14%	20%
	Tabanidae	*Chrysops*	249	PR	10%	20%
	Tabanidae	*Tabanus*	249	PR	3%	10%
	Culicidae	sp.	221	GC	10%	30%
	Stratiomyidae	*Caloparyphus*	245	GC	7%	20%
	Dolichopodidae	sp.	226	PR	3%	10%
	Syrphidae	*Eristalis*	521	GC	10%	20%
:Coleoptera	Dytiscidae	*Laccophilus*	23	PR	21%	40%
	Dytiscidae	*Agabus*	16	PR	3%	10%
	Dytiscidae	*Hydroporus*	hyd	PR	14%	20%
	Hydrophilidae	*Enochrus*	eno	CG	14%	30%
	Hydrophilidae	*Tropisternus*	69	PR / CG	17%	30%
	Hydrophilidae	*Berosus*	59	CG	7%	20%
	Gyrinidae	*Gyrinus*	50	PR	3%	10%
	Scirtidae	*Cyphon*	cyp	SC	7%	20%
Crustacea: Amphipoda	Hyalellidae	*Hyalella azteca*	489	GC	31%	40%
Crustacea: Isopoda	Asellidae	*Caecidotea*	493	GC	14%	20%
Mollusca: Gastropoda	Lymnaeidae	*Stagnicola*	503	SC	24%	30%
Mollusca: Gastropoda	Physidae	*Physella (Physa)*	504	SC	45%	70%
Mollusca: Gastropoda	Planorbidae	*Gyraulus*	505	SC	17%	40%
Annelida (Hirundinea)	Erpobdellidae	sp.	1	PR	7%	20%
Annelida (Hirundinea)	Glossiphoniidae	*Helobdella*	3	PR	3%	10%
Annelida (Oligochaeta)	Naididae	sp.	5	GC	3%	10%
Platyhelminthes (Turbellaria)		sp.	513	PR	3%	10%
**** Terrestrial Taxa Collected:***						
Mollusca: Gastropoda	Succineidae	*Oxyloma*	Unk		n/a	n/a
Coleoptera	Tenebrionidae	sp.	Unk		n/a	n/a

Notes: Summary table provided by Dr. Larry Gray (Utah Valley University). [1] Feeding groups: GC = gatherer-collector, OM = omnivore, PH = piercer-herbivore, PR = predator, SC = scraper, SH = shredder. [2] Proportion of sites where taxa was collected (29 samples were collected); taxa with relative frequency <7% were aggregated by Taxon Code or omitted from further analysis. (n/a) Terrestrial invertebrates were not included in analysis.

Group 4 taxa include two midges (Orthocladiinae and Chironominae), a fly (*Eristalis*), a dragonfly (*Erythemis*), a water boatman (*Corisella*) and an aquatic beetle (*Berosus*), representing collector-gatherers and predators. A fifth group becomes clear from the third NMDS Axis, where *Hyalella* (amphipod) and *Notonecta* (backswimmer) appear to be associated with sites receiving groundwater inflows with high specific conductivity.

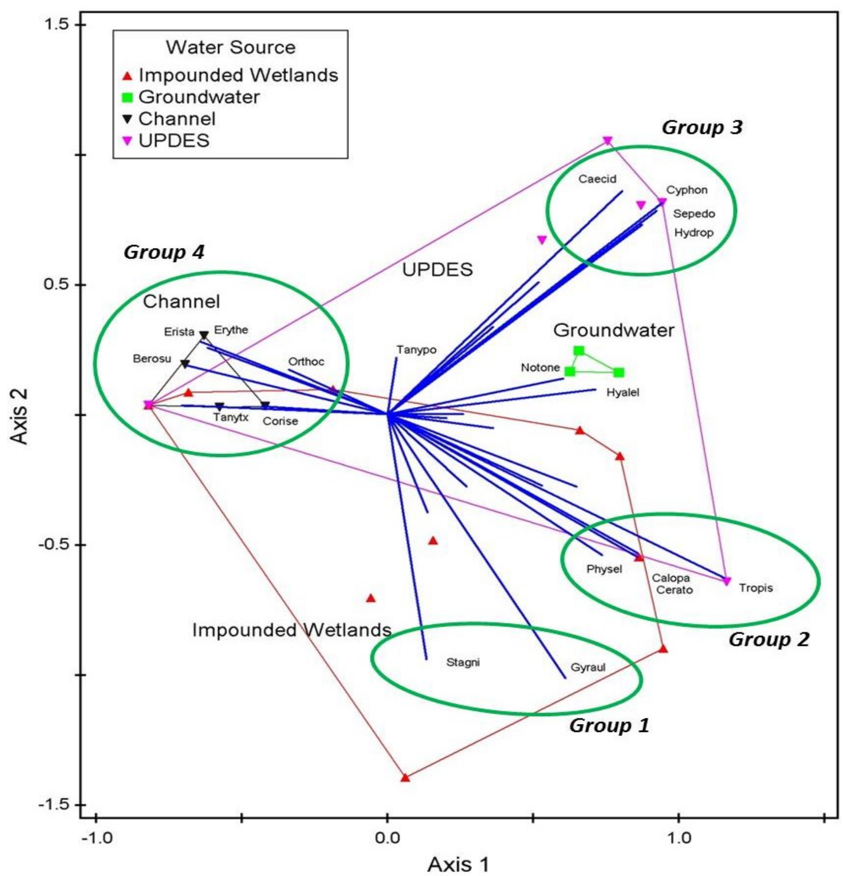

Figure 7. NMDS ordination of macroinvertebrate community data.

Table 11. Summary of Benthic Macroinvertebrate Community Composition Data.

Site	Distance [1]	Total Count [2]	Rank of Counts	Taxa [3] Richness	Rank of Richness	Site Richness	Evenness [4]	Diversity (Shannon's H') [5]	Simpson's Diversity [6]
ADCO	100	6733	4	16	2	22	0.49	1.37	0.67
	300	391	12	8	9		0.18	0.36	0.14
	500	8649	2	13	5		0.23	0.60	0.35
BR-U2D	100	83	15	2	18	1	0.00	0.00	0.00
	300	1	29	1	26		0.00	0.00	0.00
	500	3	28	2	18		0.00	0.00	0.00
CDSD-01	100	*- NA -*				5	*- NA -*		
	300	24	24	3	17		0.43	0.30	0.16
	500	29	22	4	15		0.74	1.02	0.59
CDSD-02	100	5	26	2	18	17	0.97	0.67	0.48
	300	788	10	16	2		0.14	0.38	0.12
	500	297	13	9	7		0.42	0.93	0.44
FB-SERP	100	4	27	2	18	10	0.81	0.56	0.38
	300	46	19	11	6		0.77	1.68	0.76
	500	10	25	2	18		1.00	0.69	0.50
GOGGDR	100	28	23	4	15	4	0.64	0.88	0.50
	300	63	17	1	26		0.00	0.00	0.00
	500	58	18	1	26		0.00	0.00	0.00
HC-East	100	40	21	5	12	19	0.77	1.24	0.64
	300	912	8	19	1		0.48	1.32	0.53
	500	1204	7	15	4		0.67	1.81	0.75
NDSD	100	10800	1	1	26	1	0.00	0.00	0.00
	300	1500	5	2	18		0.00	0.00	0.00
	500	8200	3	2	18		0.00	0.00	0.00
PROM-01	100	1363	6	5	12	8	0.06	0.09	0.03
	300	76	16	5	12		0.43	0.70	0.38
	500	822	9	2	18		0.03	0.02	0.00
TNCKC	100	621	11	6	11	12	0.75	1.20	0.65
	300	154	14	8	9		0.33	0.63	0.30
	500	44	20	9	7		0.59	1.22	0.52

Notes: [1] Distance from inflow, along main flowpath, in meters. [2] Total number of individuals observed from a composite sample of 3 to 5 sweeps (see Section **Error! Reference source not found.** for details). A minimum count of > 300 individuals is preferred for appropriate evaluation of community composition: 16 of 29 samples had insufficient observations. [3] Number of distinct taxonomic units observed within sample; the lowest level of identifiable resolution may be species for some organisms, but a higher level (e.g. genus or even sub-family) may be required for others. [4] Evenness calculated as H' / ln(*Richness*). [5] Shannon's Diversity Index (H') calculated as $-\sum p_i/\ln(p_i)$. [6] Simpson's Diversity Index calculated as $1-\sum(p_i)^2$; p_i is relative abundance of element *i*.

Table 12. Potential associations between macroinvertebrate taxa and Invertebrate-NMDS axis 1-3 scores.

Taxon Code	LTU name	NMDS Axis 1			NMDS Axis 2			NMDS Axis 3		
		Pearson (r)	R^2	Kendall's Tau (τ)	Pearson (r)	R^2	Kendall's Tau (τ)	Pearson (r)	R^2	Kendall's Tau (τ)
84	Tantytarsini + Chironomini	-0.95	0.90	-0.85						
504	Physella	0.52	0.27	0.51	-0.55	0.30	-0.41			
489	Hyalella	0.47	0.23	0.41				-0.80	0.65	0.37
493	Caecidotea	0.43	0.18	0.33	0.66	0.43	0.49			
503	Stagnicola				-0.65	0.42	-0.40			
505	Gyraulus				-0.58	0.34	-0.36			
89	Tanypodinae							0.50	0.25	0.25

Strength of associations based on Pearson's (r) and Kendall's Tar (τ) statistics, where correlation and rank-correlation scores > 0.4 and < -0.40.

Table 13. Potential associations between site variables and Invertebrate-NMDS axis 1-3 scores.

Taxon Code LTU name	NMDS Axis 1			NMDS Axis 2			NMDS Axis 3		
	Pearson (r)	R^2	Kendall's Tau (τ)	Pearson (r)	R^2	Kendall's Tau (τ)	Pearson (r)	R^2	Kendall's Tau (τ)
Max. plant height	0.42	0.18	0.31						
Dissolved O_2 conc.	-0.46	0.21	-0.39						
Total dissolved P	0.49	0.24	0.22	0.42	0.17	0.18			
Dissolved Organic C	0.41	0.17	0.34						
Thickness of raised litter				0.47	0.22	0.42			
# of Metal Exceedences				0.46	0.21	0.27			
Specific Conductivity							-0.70	0.49	-0.37

Strength of associations based on Pearson's (r) and Kendall's Tar (τ) statistics, where correlation and rank-correlation scores > 0.4 and < -0.40.

4.3 Water Chemistry

Great Salt Lake fringe wetlands represent areas of emergent marsh to hemi-marsh where water regimes range from permanently to seasonally flooded in most years. As such, the aquatic features of these wetlands can vary from small, nearly isolated patches of open water within dense emergent vegetation to extensively flooded areas containing both emergent and submergent vegetation as well as mats of benthic periphyton. The sampling objective was to characterize the overall chemical environment of surface waters that serve as both inputs and losses of constituents to the wetland, as a function of distance from the main inflow to the system.

Summary statistics for 40 measured and derived water quality variables are shown in Table 14. This table includes benchmarks for a subset of variables (as available) as context for interpreting these data and information on minimum reporting limits from laboratory analyses.

Standard water quality parameters include temperature, pH, specific conductance, dissolved O_2 and chlorophyll-a, and describe the general physical and chemical conditions controlling aquatic metabolism in surface waters. Water samples collected within the main flowpath of fringe wetlands spanned a modest range of variability in water temperature (14.0 °C) and pH (2.1), while variation in water salinity (specific conductance and TDS), dissolved oxygen (DO) and chlorophyll-a concentrations was much greater. For example, DO concentrations varied by 16 mg/L among samples (equivalent to a range of 229% of saturation), and chlorophyll-a concentrations (filtered from the water column) varied by more than 200 μg/L.

Samples were generally within the expected range for standard water quality parameters. Only one measurement of pH was observed to outside the standard water quality benchmark for surface waters (< 6.5 or > 9.0). Much of the variation for these parameters was observed within sites and may reflect a primary control of shading by emergent vegetation (cooler temperatures, lower DO and chlorophyll-a) vs. shallow open water areas (warmer temps, and higher DO and chlorophyll-a).

Concentrations of nutrients and detrital organic matter within the water column were also quite variable among samples. Lower quartile (25th percentile) values for inorganic N species (NH_4^+, NO_3^-) were similar to values for impounded wetlands adjacent to Great Salt Lake, while lower quartile values for total dissolved P and suspended solids were 5 to 10 times higher in fringe vs. impounded wetlands (CH2MHill, 2014). Three samples had higher NO_3^- concentrations than the 'pollution indicator' benchmark (Table 14), and four samples exceeded the benchmark for NH_3 toxicity. In addition, 29 of 30 samples had total P concentrations greater than the 0.05 benchmark.

Table 14. Summary Characteristics of Water Chemistry Parameters for Fringe Wetlands

Parameter	Units	MRL	Samples below MRL	Percentiles *			Range	Samples Exceeding	Benchmark	Comments
				25th	Median	75th				
Standard Water Quality Parameters										
Temperature	° C			21.72	23.25	26.15	14.04			
pH	-			7.22	7.61	8.17	2.1	1	<6.5 or >9.0	See Note [1]
Specific Conductance	µS/cm			1,483	2,636	4,004	15,860	3	7,500	Tolerance for freshwater marsh (See Keate, 2005)
Total Dissolved Solutes (TDS)	mg/L	10		826.5	1,412	2,395	8,692			
Dissolved O_2	mg O/L			1.42	4.04	6.37	16.07	11	3.0	See Note [1]; Exceedance refers to DO concentrations *below* the benchmark.
Dissolved O_2	% saturation			20.7	53.2	89.3	229.3			
Chlorophyll-a	µg/L			4.0	9.0	26.9	209.0			
Nutrient and Organic Matter Concentrations										
Ammonium (NH_4)-N, total	mg N/L	0.05	6	0.061	0.234	1.215	4.177	4	2.23	See Notes [1] and [2]. Benchmark shown is based on the median values for pH and Temp (pH 7.6 and Temp 23.2 °C), for ammonia toxicity.
Nitrate + Nitrite (NO_3 + NO_2)-N, total	mg N/L	0.1	16	0.037	0.075	0.663	11.296	3	[4.0]	See Note [3]
Organic N, total	mg N/L			0.72	1.31	3.38	25.37			
Total N, total	mg N/L	0.2		1.17	1.90	7.57	27.72			
Phosphorus, total (digested)	mg P/L	0.02		0.240	0.938	2.377	14.780	29	[0.05]	See Note [4]
TN:TP ratio	-			1.53	2.78	8.63	41.47			
Organic Carbon, total	mg C/L	0.5		6.57	9.25	17.12	43.78			
TOC:TON ratio	-			5.17	7.13	11.63	16.79			
Suspended Solids, total (TSS)	mg/L	4	1	19.0	80.5	401.0	5,978.0			
Volatile Solids, total (TVS)	mg/L	5	3	8.1	21.0	108.7	3,828.0			
TVS:TSS ratio	-			0.28	0.43	0.64	0.90			
Major Anion and Cation Concentrations										
Sulfate (SO_4)	mg S/L	20		56.42	86.70	190.25	355.20			
Chloride (Cl)	mg Cl/L	1		251.2	478.5	934.7	1,536.4			
Flouride (F)	mg F/L	0.05	2	0.40	0.62	0.79	1.96			
Calcium (Ca)	mg Ca/L	1		66.67	75.70	93.02	271.60			
Magnesium (Mg)	mg Mg/L	1		38.52	49.35	71.27	137.60			
Potassium (K)	mg K/L	1		17.05	21.70	35.62	87.04			
Sodium (Na)	mg Na/L	1		168.2	337.5	583.7	2,433.2			
Iron (Fe)	mg Fe/L	0.02	1	0.17	0.56	1.42	30.48	8	1.0	See Note [1].
Manganese (Mn)	mg Mn/L	5	2	28.07	97.85	297.75	6102.50			
Hardness, total (as $CaCO_3$)	mg $CaCO_3$/L			328.4	392.8	482.8	1193.5			
Trace Metal Concentrations										
Aluminum, total (Al)	µg Al/L	10	1	98.7	352.5	811.2	30,135	8	750	See Note [1]; acute value for total recoverable metal.
Arsenic, total (As)	µg As/L	1		5.6	9.1	10.8	33.8	-	340	See Note [1]; acute value for total recoverable metal.
Barium, total (Ba)	µg Ba/L	0.1	12	0.05	0.13	0.15	1.18	1	1.0	See Note [5].
Cadmium, total (Cd)	µg Cd/L	0.1	25	0.05	0.05	0.25	2.35	1 / 0	0.75 / 8.57	See Notes [1] and [6]. Benchmarks shown are median of calculated site values.
Cobalt, total (Co)	µg Co/L	30	30	15	15	15	0	30	3.0 *	See Note [7]. Note that screening level is 5x lower than MRL
Copper, total (Cu)	µg Cu/L	1		3.78	5.80	13.96	2,886.27	2 / 2	30.0 / 50.8	See Notes [1] and [6]. Benchmarks shown are median of calculated site values.
Nickel, total (Ni)	µg Ni/L	5	24	2.5	2.5	2.5	62.5	- / -	166.0 / 1493	See Notes [1] and [6]. Benchmarks shown are median of calculated site values.
Lead, total (Pb)	µg Pb/L	0.1	5	0.43	2.56	5.60	93.45	4 / 0	18.2 / 466	See Notes [1] and [6]. Benchmarks shown are median of calculated site values.
Selenium, total (Se)	µg Se/L	1	12	0.50	1.34	1.93	5.37	1 / 0	4.6 / 18.4	See Note [1].
Mercury, total (THg)	µg THg/L	0.2	30	0.1	0.1	0.1	0	30	0.012	See Note [1]. Note that screening level is 8x lower than MRL.
Zinc, total (Zn)	µg Zn/L	10	16	5.0	5.0	27.7	1,203.6	2	381.9	See Notes [1] and [6]; acute and chronic values are equivalent.
Toxic Ligands										
Hydrogen Sulfide, total (H_2S)	mg S/L	0.1	23	0.05	0.05	0.05	1.758	24	0.002	See Note [1]; value is a function of pH (see Note [8].

Notes: [*] 30 samples were collected for each parameter; 3 locations from 10 sites.
[1] See R317.2, Table 2.14.2 for Aquatic Wildlife Use (3D).
[2] For ammonia toxicity, chronic criteria is a function of both pH and temperature.
[3] Nitrate listed as a pollution indicator in R317.2, Table 2.14.2 for Aquatic Wildlife Use, but no value provided for use class 3D. Wildlife use classes 3B (warm water fish) and 3C (non-game fish) have value of 4.0.
[4] Total phosphorus listed as pollution indicator in R317.2, Table 2.14.2 for Aquatic Wildlife Use (3B) value of 0.05; value for lakes and reservoirs is 0.025.
[5] See R317.2, Table 2.14.1 for Human Health Use (1C); no value for Aquatic Wildlife.
[6] First value is total recoverable value for chronic criteria, corrected for hardness; second value is acute value (also corrected).
[7] Value is from Screening Quick Reference Tables (SQuiRT) for surface water (FW) (see: Link to NOAA).
[8] The proportion of undissociated $H_2S_{(aq)}$ from total hydrogen sulfide (measured value) was calculated from a thermodynamic model at 25 °C under freshwater conditions (ionic strength of 0.05 mM), and fitted to a sigmoidal curve: $H_2S_{(aq)}/H_2S_{total} = 1 - \left[1/\left(1+e^{-\left((pH-\beta_0)/\beta_1\right)}\right)\right]$; where β_0 = 7.018, and β_1 = 0.434, estimates of the mean and standard deviation of 50 data points for pH from 4.0 to 10.0.

Since nearly all benchmarks in Table 14 were developed for freshwater systems, it is not clear whether they have any functional or ecological significance for fringe wetlands, particularly the very slow flow areas dominated by emergent marsh. Comparison of data against benchmarks derived for freshwater streams suggests that the relative concentration of P vs. N of fringe wetlands are higher than for streams (i.e. narrower TN:TP ratio). Interestingly, soluble organic N represents a clear majority of the total N pool within the waters of fringe wetlands (22 of 30 samples); this supports the idea that many wetlands function as nutrient and biomass 'transformers' from inorganic to organic forms.

Across all samples, the concentrations of major ions ranged from 400 to over 5000 mg/L (TDS) (Table 14). Dominant cations were Na^+, Mg^{2+}, Ca^{2+}, and K^+, while the dominant anions were Cl^-, SO_4^{2-}, and HCO_3^- (estimated from total alkalinity). Na^+ and Cl^- ions were nearly always the dominant ions. The relative abundance of major ions (adjusted for charge differences) from surface waters of these fringe wetlands varied widely among samples, with a substantial amount of overlap among dominant water sources (Figure 8). For example, wetlands receiving water from impounded wetlands had lower proportions of Ca^{2+} + Mg^{2+} vs. Na^+, and lower alkalinity (as HCO_3^-), relative to sites downstream of wastewater treatment plants. Channel sites spanned a wide range of ionic composition, from Ca/Mg-CO_3 (Kay's Creek) to Na-Cl (Goggin Drain), although within-site differences were small. Sites that had urban or suburban influences (e.g. receiving waters from WWTPs, suburban streams, or the Jordan river) had higher Ca/Mg vs. Na ratios, however, other factors could be driving this apparent pattern. The relative composition of major ions varied with the quantity of dissolved ions (as TDS). Both Na^+ and Cl^- increased with TDS, while Ca^{2+}, Mg^{2+}, and HCO_3^- decreased with increasing TDS (data not shown). Hardness of surface waters, based on Ca and Mg only, was high relative to other nearby aquatic systems; 25th and 75th percentiles were 328.4 and 482.8 mg $CaCO_3$/L, respectively.

Concentrations of other major ions, including F and Fe, were typically low; however, eight samples had Fe concentrations greater than the benchmark of 1.0 mg Fe/L (Table 14). Interestingly, high concentrations of Mn were observed in about 25% of samples, where Mn was a substantial contribution (over 30%) to major cation concentrations. Since these samples were unfiltered, it is possible that a small and easily digestible flocc contributed to these high Mn values; this idea is supported by the higher TSS (1285 vs. 336 mg/L) and TVS (746 vs. 195.6 mg/L) in samples with high Mn values compared to the remaining samples. This observation points to the wide range of microsite conditions within marsh wetlands, since the redox state can vary widely at small, moderate, and large spatial scales, and Mn solubility is strongly tied to redox of soils and overlying waters.

Concentrations of several trace metals in surface waters ranged from less than laboratory reporting limits to values that exceed acute benchmarks aquatic wildlife use (Table 14). DWQ continues to engage with partner laboratories in an effort to optimize analytical sensitivity against sample analysis cost, particularly in waters where factors such as salinty may degrade instrument sensitivity, either by sample dilution or measurement interference, such as wetlands adjacent to Great Salt Lake. Five trace metals had more than 50% of samples below the reporting limit, while two metals (Co and THg) had reporting limits that exceeded the benchmark value. A reasonable goal going forward is for laboratory minimum reporting limits (MRLs) to be at least an order of magnitude lower than the lowest benchmark or screening level. Aluminum was most commonly observed to exceed the wildlife use benchmark shown in Table 14, and Cu, Pb and Zn had at least two samples with concentrations higher than benchmarks. Benchmarks for five metals (Cd, Cu, Ni, Pb, and Zn), based on aquatic wildlife uses in Table 14, are calculated as a function of water hardness and the numeric values increase as hardness increases, up to a maximum value (at 400 mg/L); over 25% of fringe wetland samples had hardness > 400 mg/L.

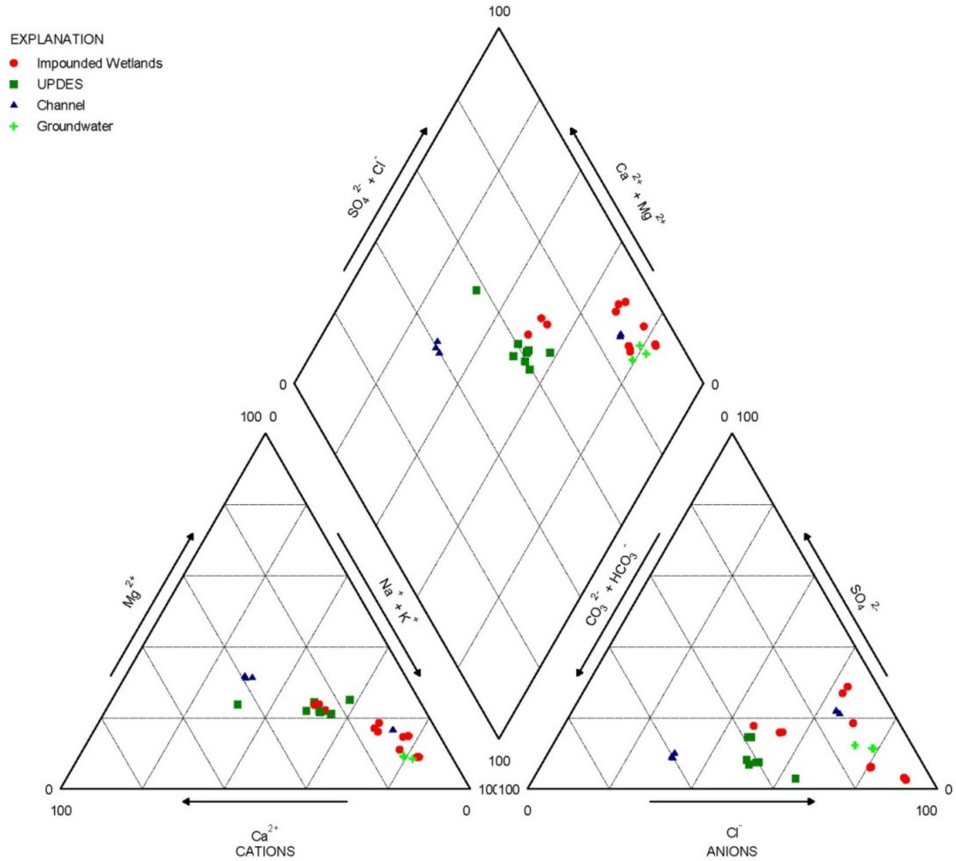

Figure 8. Major ions of Fringe Wetlands, by dominant water source.

Lastly, H_2S, an important component of reducing environments in wetlands and a potentially toxic ligand to aquatic life, was measured in water samples. Calculation of the benchmark value requires measurement of pH *in situ* (similar to NH_4^+ benchmark (as NH_3)). As can be seen in Table 14, many H_2S samples from fringe wetlands were both lower than the standard reporting limit for this analyte and higher than the aquatic wildlife benchmark. Additional work on the presence of H_2S in wetland soils as well as laboratory refinements will continue to examine the significance and controls on H_2S levels within the water column of wetlands.

4.3.1 Ordination of Water Chemistry Data

A combination of water chemistry variables was used to explore potential patterns among water quality variables (Figure 9). An optimum NMDS solution for the combined water chemistry data was obtained after recalculating values relative to the maximum observed for each variable, and using the Euclidean distance measure. The solution contained two axes and a final stress of 10.6. Given the limited number of sites, there was modest evidence for an association between 9 nutrient variables and 6 metals plus 6 major ion variables for NMDS axes 1 and 2, respectively (see Table 15). Axis 1 was most strongly associated with NH_4^+, TN, and TSS concentrations, while axis 2 was most strongly (negatively) associated with Ca, Pb, Fe and Mg concentrations. Similar to other ordinations for plant and macroinvertebrate community composition shown above, sites receiving water from channel or groundwater sources were quite distinct, while there was a considerable amount of overlap among sites downstream of impounded wetlands or UPDES facilities. Trace metal concentrations appear to be driving much of the observed variation within and among sites downstream of UPDES facilities, compared to sites below

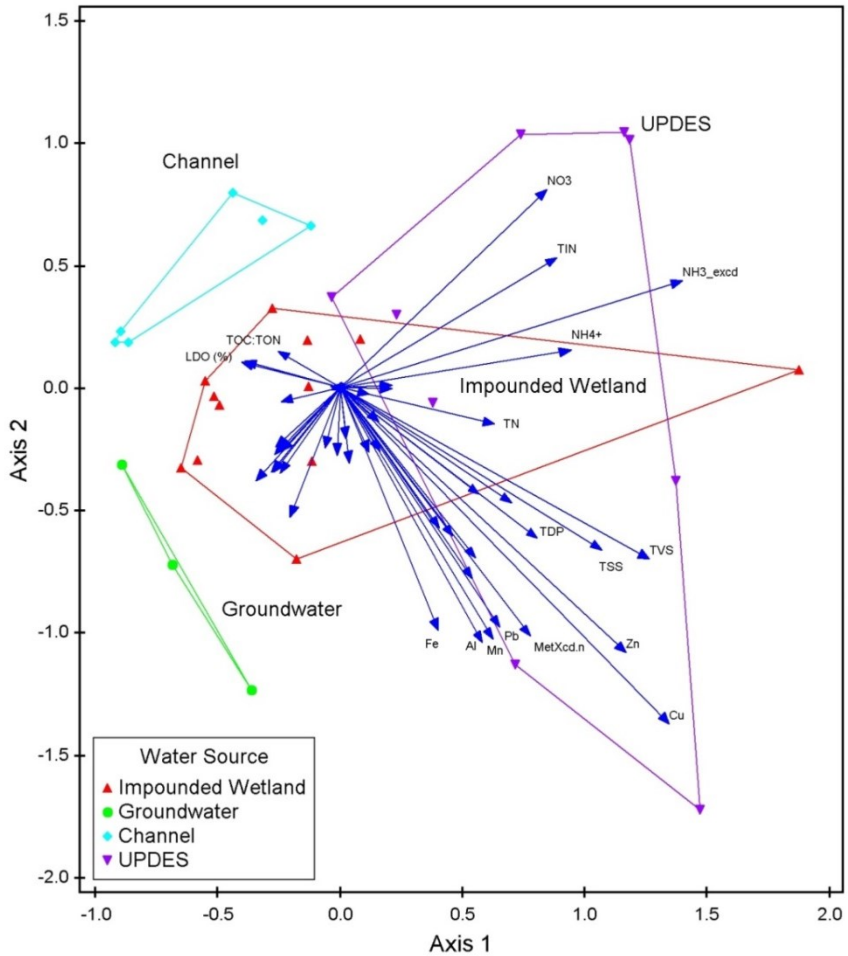

Figure 9. NMDS Ordination of water chemistry data.

impounded wetlands, however, variations in N species (NH_4^+, NO_3^-, and soluble organic N) likely also play a role. Sampling of additional fringe wetlands from a wider range of water sources will help clarify the relative importance and degree of overlap among multiple stressors.

4.1 Supplemental Indicators

4.1.1 Wetland Soils

Soils encountered within these fringe wetland sites varied across a range of soil moisture (moist to severely inundated), particle size (gravelly loam to silty clay), and substrate (mucky peat to mineral) conditions. At the current time, laboratory protocols for several important wetland-soil characteristics are being worked out in collaboration with collaborators from Utah State University, in an effort to build on water quality characteristics that apply to wetlands. These measurements include: soil total and extractable P, soil salinity, organic matter content, plant C, N and P concentrations, and plant and soil stable $\delta^{13}C$ and $\delta^{15}N$ signatures. Results to date for fringe wetlands include soil extractable nutrients and acid-digestible metals, and are described below.

Table 15. Potential associations between water chemistry variables and Water Chem-NMDS axis 1 and 2 scores.

Chemistry Group	Analyte	NMDS Axis 1			NMDS Axis 2		
		Pearson (r)	R^2	Kendall's Tau (τ)	Pearson (r)	R^2	Kendall's Tau (τ)
Nutrients	NH_4^+	0.852	0.726	0.574			
Nutrients	TDP	0.585	0.343	0.462			
Nutrients	TSS	0.63	0.397	0.157			
Nutrients	TVS/TSS	0.544	0.296	0.424			
Nutrients	TKN	0.53	0.281	0.563			
Nutrients	TN	0.673	0.453	0.582			
Nutrients	TOC:TON	-0.624	0.389	-0.453			
Nutrients	DO (% sat.)	-0.572	0.327	-0.532			
Nutrients	pH (field)	-0.571	0.326	-0.412			
Nutrients	TON				-0.583	0.34	-0.361
Trace Metals	Al				-0.688	0.473	-0.356
Trace Metals	Ba				-0.659	0.435	-0.523
Trace Metals	Cd				-0.567	0.322	-0.238
Trace Metals	Ni				-0.635	0.403	-0.544
Trace Metals	Pb				-0.728	0.531	-0.407
Trace Metals	Zn				-0.559	0.313	-0.273
Major Ions	TDS				-0.589	0.347	-0.554
Major Ions	Fe				-0.718	0.516	-0.411
Major Ions	Mn				-0.65	0.423	-0.354
Major Ions	Cl				-0.578	0.334	-0.562
Major Ions	Ca				-0.768	0.59	-0.582
Major Ions	Mg				-0.724	0.524	-0.621
Major Ions	Na				-0.574	0.33	-0.555

Strength of associations based on Pearson's (r) or Kendall's Tar (τ) statistics, where correlation and rank-correlation scores >0.5 and <-0.5.

4.1.1.1 Soil extractable nutrients

Soil moisture content ranged from moist (0.30 g H_2O/g soil) to supersaturated (over 2.0 g H_2O/g soil) in submerged soils (Figure 10), indicative of the wide variety of environments within and among the fringe wetlands samples here. Three sites, Central Davis (01), FB-Serpentine, and Kay's Creek, had the widest range of soil moisture contents, from approximately 0.80 to well over 3.0 g H_2O/g soil, and the highest mean water depths.

Water-extractable $SO_4^=$ concentrations varied by more than an order of magnitude (Figure 10) among samples. Water-extractable $SO_4^=$ commonly represents less than 20% of total soil S, and can be released from soil organic matter in response to water level fluctuations (Ye, et al., 2010; Steinman et al., 2014). While S is an essential plant and microbial nutrient, water column and soil $SO_4^=$ concentrations in these wetlands (25th and 75th percentiles: 56 to 190 mg S/L and 199 to 490 mg S/kg, respectively) are unlikely to be limiting to plant growth requirements or anaerobic microbial processes (Reddy and DeLaune, 2008; Kadlec and Wallace, 2009). This is particularly true for sulfate reduction (to sulfide) processes, where there appears to be ample $SO_4^=$ available as an electron acceptor.

Extractable NH_4^+ pools were quite high in four sites relative to the other sites, Central Davis (#2), FB-Serpentine, North Davis, and Kay's Creek, where NH_4^+-N exceeded 30 mg/kg soil (Figure 11). While two of these sites received treated waste water effluent, the remaining sites receive water from an extensive impounded wetland system and a suburban stream, suggesting that waste water treatment plants are not the sole source of N enrichment to fringe wetlands. In contrast, most NO_3^- samples were reasonably low (< 1.5 mg NO_3—N/kg), indicative of strongly reducing conditions in these soils. Forthcoming measurements of soil total organic C and total N concentrations and $\delta^{15}N$ stable isotope signatures from these and additional sites may shed light on the size of nutrient and organic matter sinks within this wetland type.

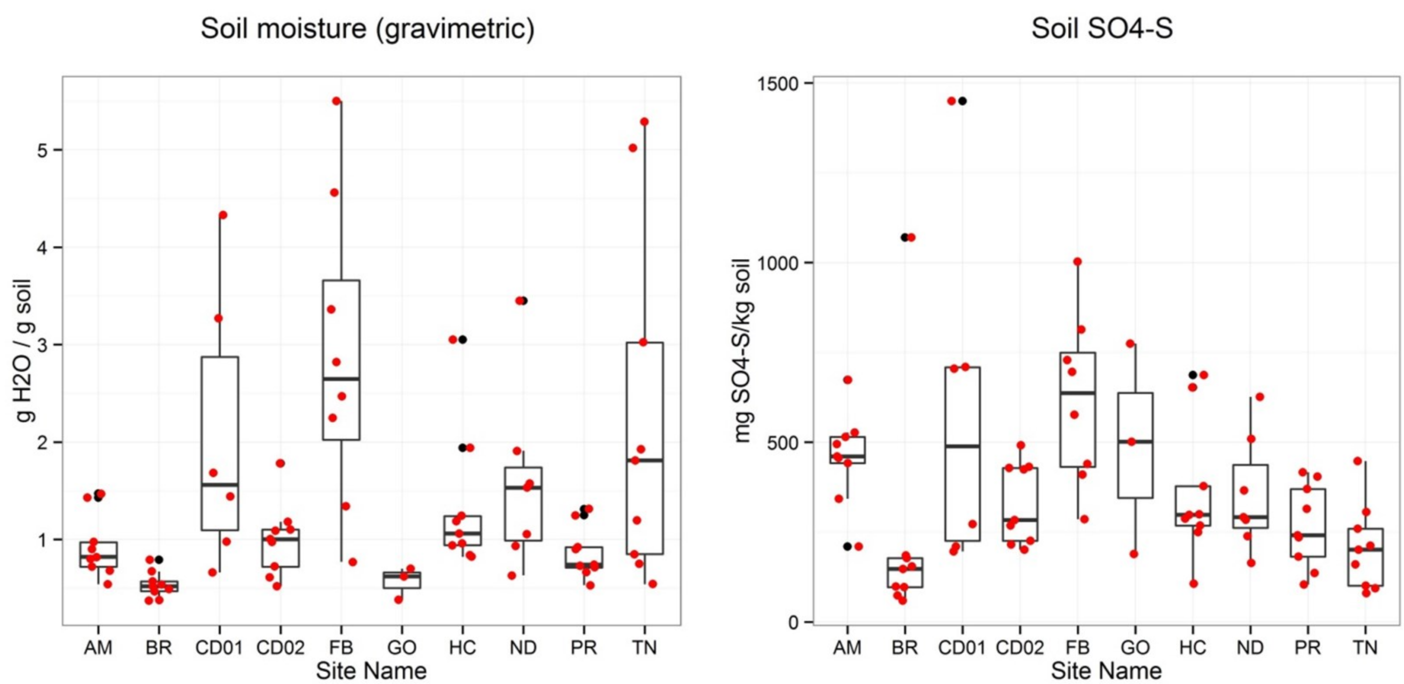

Figure 10. Distribution of soil gravimetric moisture (left) and extractable sulfate (right) across sites.

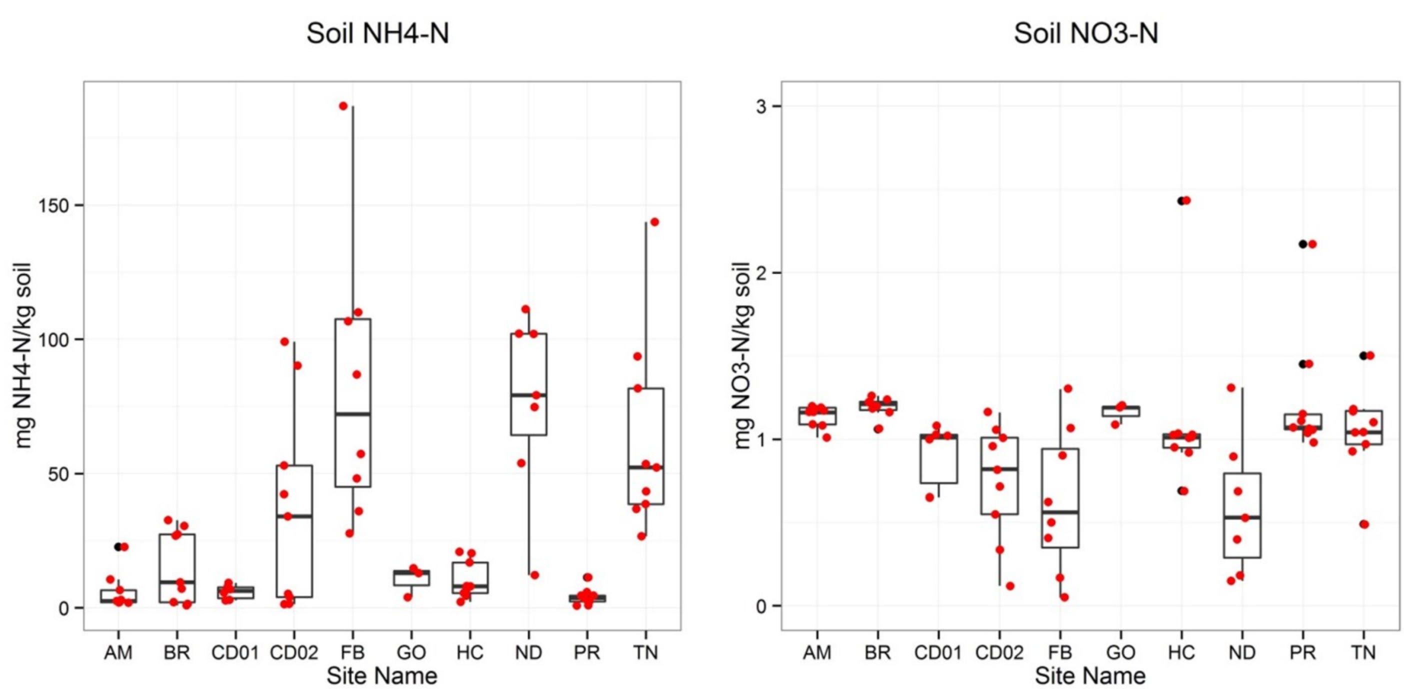

Figure 11. Distribution of soil extractable NH_4^+ (left) and NO_3^- (right) across sites.

4.1.1.2 Soil trace elements

The abundance of trace elements in wetland soils reflect a variety of sources and processes, from geologic substrates liberated by soil forming processes to historical and contemporary loads driven by human-induced disturbance (e.g. mining and mineral processing, industrial discharges, roads, and agricultural use (soil erosion, irrigation return)). The distribution of concentrations for 13 trace elements from surface soils (0-10 cm) of fringe wetlands is described in Table 16. Average values for transects exceeded benchmark levels for four elements: As, Ba, Cd, and Pb (Table 16). These elements are commonly associated with industrial, and to a lesser extent agricultural sources, while a substantial amount of lead (Pb) deposition may be associated with the historical (and currently discontinued) practices of smelting and the use of alkyl-Pb additives in automobile fuels (Alloway, 2012; DWQ, 2015). Trace elements in soils occur as a wide array of chemical species (e.g. as carbonates or sulfides) and many are strongly sorbed to clay mineral or Fe/Mn-oxide surfaces. As such, bioavailability to sensitive organisms is expected to be lowest in soils, compared to surface waters, particularly since $CO_3^{=}$ and HS^{-} ligands are often abundant in this wetland type. The distributions of metals extractable by the cold-acid digest method for all sites are included at the end of this document (Figure 19 to Figure 25).

The combined dataset of soil metals and extractable nutrients, aggregated by transect, was examined by NMDS ordination, after relativizing the values to the maximum for each variable, using the Euclidean distance measure. The optimum solution contained three axes with a final stress of 6.9. For simplicity, only the first two axes are shown, which account for over 80% of the variation (Figure 12). Axis 1 generally increases with soil metal concentrations. There is substantial overlap among water sources, except for sites dominated by groundwater inputs which generally have lower soil metal concentrations.

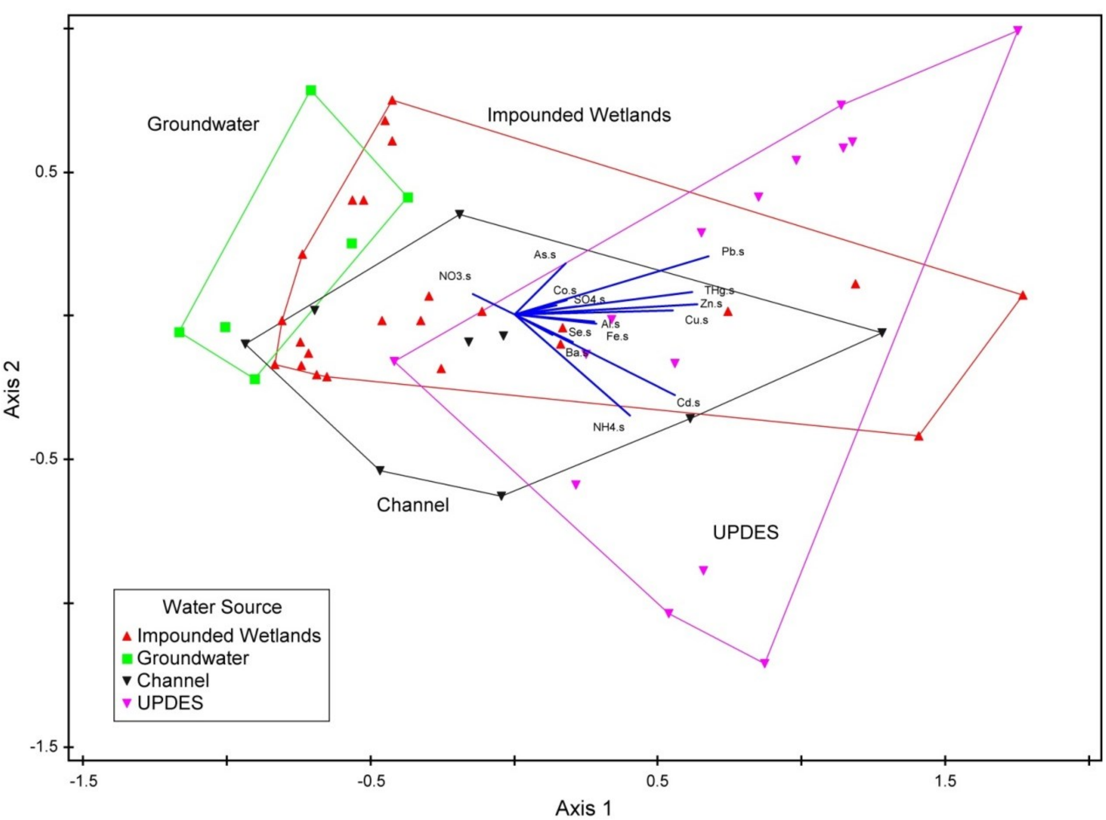

Figure 12. NMDS Ordination of sediment chemistry data.

Table 16. Summary Characteristics of Wetland Soil Trace Element and Extractable Nutrient Concentrations

Parameter	Units	Percentiles *			Range	Background Level **	Benchmark (PEL) **	# Transects Exceeding §	Comments
		25th	Median	75th					
Trace Elements									
Aluminum (Al)	mg Al/kg	1,765	2,717	3,563	2,309	2,600	18,000	0	
Arsenic (As)	mg As/kg	2.31	5.97	10.40	22.88	1.1	17.0	1	Associated with agricultural and industrial sources
Barium (Ba)	mg Ba/kg	79.7	102.2	128.6	302.6	67 ‡	130	7	See Note [1] for benchmark; Industrial sources
Cadmium (Cd)	mg Cd/kg	0.25	0.38	1.14	8.62	0.2	3.5	2	See Note [2] for benchmark; Agricultural sources
Cobalt (Co)	mg Co/kg	1.83	2.55	3.38	7.51	1.85 †	10	0	See Note [3] for benchmark; Industrial sources
Copper (Cu)	mg Cu/kg	6.85	17.73	40.86	102.15	25	197	0	Associated with agriculture, industry, and road sources
Iron (Fe)	mg Fe/kg	2,663	4,194	6,128	13,392	2,950 †	40,000	0	See Note [4] for benchmark
Manganese (Mn)	mg Mn/kg	221.2	315.5	402.3	721.5	400	1,100	0	See Note [4] for benchmark
Nickel (Ni)	mg Ni/kg	3.91	5.28	7.88	19.79	9.9	36	0	Associated with agricultural and industrial sources
Lead (Pb)	mg Pb/kg	10.5	27.8	66.4	263.8	10.5	91	5	Associated with roads and industrial sources
Selenium (Se)	mg Se/kg	0.08	0.10	0.13	0.42	0.29	1.0	0	See Note [3] for benchmark
Mercury, total (THg)	µg THg/kg	24.2	46.2	124.4	534.2	27.5	486	0	See Note [5] for benchmark
Zinc (Zn)	mg Zn/kg	25.3	37.5	120.8	303.4	22.5	315	0	See Note [6] for benchmark; Associated with agriculture and industrial sources
Extractable Nutrients									
Extractable Ammonium (NH_4^+)	mg N/kg	3.85	11.70	49.14	186.10				
Extractable Nitrate (NO_3^-)	mg N/kg	0.88	1.04	1.17	9.53				
Extractable Sulfate ($SO_4^=$)	mg S/kg	199.3	294.5	492.2	1391.1				

* Percentiles calculated from all sample data for this wetland type (n=78 measurements).
** Based on values from SQuiRT tables, unless specified otherwise.
§ Based on number of transects (n=29), average of sample measurements across each transect.
‡ Background value from Alberta Environment (2009). † Background levels estimated from Johnson et al. (2012)
[1] Toxic effects level (TEL) from NOAA's Screening Quick Reference Table (SQuiRT) for marine sediments.
[2] Value for freshwater sediments given, marine sediment value is 4.2 mg/kg.
[3] Apparent effects threshold (AET) for marine sediments.
[4] Severe effects level (SEL) from SQuiRT tables.
[5] Value for freshwater sediments given, marine sediment value is 700 mg/kg.
[6] Value for freshwater sediments given, marine sediment value is 271 mg/kg.

Two groups of variables appear to have modestly distinct scores on the first two axes. The first group included Pb, THg, Cu and Zn. Soils with high scores for this group received water from impounded wetlands, waste water treatment plants, and a suburban creek. A second group included two variables: extractable NH_4^+ and Cd, which were modestly correlated with soil moisture (r = 0.44 and 0.38 , respectively). However, these two apparent 'groupings' of variables could be spurious, since the data are from a limited number (10) of fringe wetland sites. For example, the first group appears to be driven largely by the Central Davis and FB-Serpentine sites, while the second group is largely associated with the higher Cd, NH4, and moisture contents observed at the North Davis site.

4.1.2 Leaf C:N and δ15N signatures of Dominant Vegetation

Leaf samples from dominant plant species along each transect were collected and analyzed for C , N and P concentrations and $\delta^{15}N$ isotope ratios. The objective was to begin development of a database for plant nutrition and fertility indicators of important wetland species. Samples from 10 dominant species were collected from 86 locations in fringe wetlands in 2013. Data for the most common species (*Phragmites australis*, *Schoenoplectus americanus* [*Scirpus*], and *Distichlis spicata* were kept separate, both species of *Typha* were combined, aquatic plants (*Stuckenia sp.*) was kept distinct, and all other species with less than 4 samples (e.g. *Salicornia*, *Tamarix*, *Cardaria*, *Atriplex*) were aggregated. Indicators of plant nutrition, such as C:N and C:P ratios, are known to vary among species and ecosystem type as well as in response to soil nutrient availability. In general, higher (or wider) C:nutrient ratios suggest that that nutrient is relatively more limiting to plant growth than a lower C:nutrient ratio. In a similar vein, narrow N:P ratios suggest relatively greater P over N availability, while wide N:P ratios are more indicative of P limitations to growth.

Preliminary results are shown for leaf C:N (Figure 13), C:P (Figure 14), N:P, (Figure 15) and $\delta^{15}N$ (Figure 16) ratios among species and dominant water sources. Leaf C:N ratios are narrow and similar among species in fringe wetlands

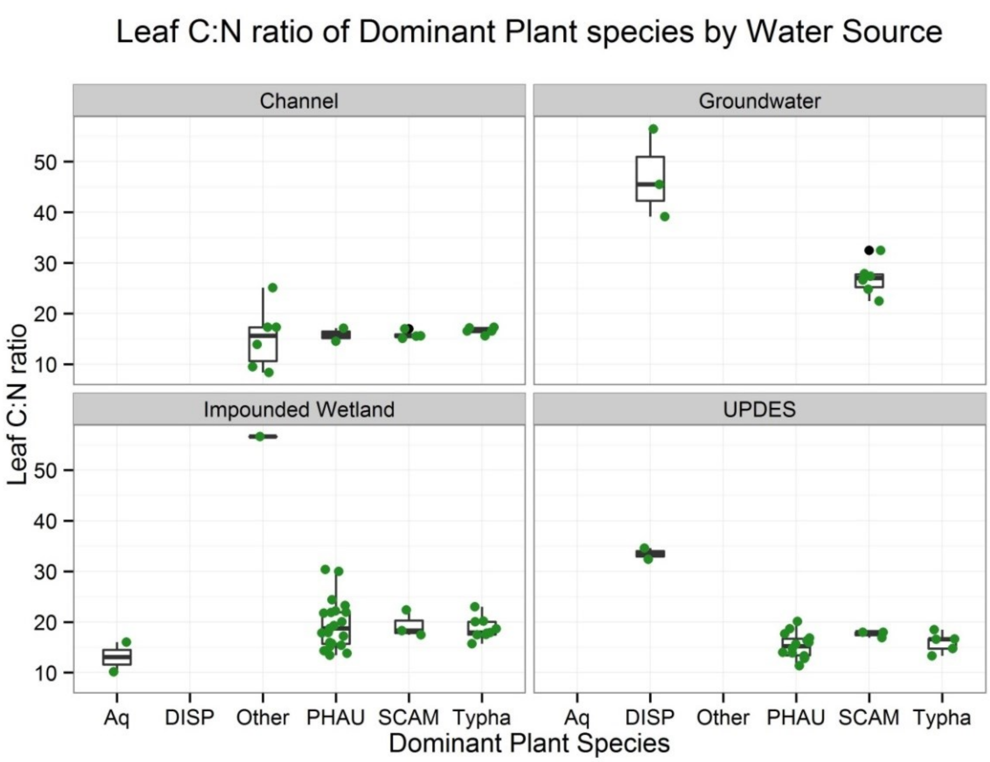

Figure 13. Leaf C:N ratio of dominant plant species, by water source.

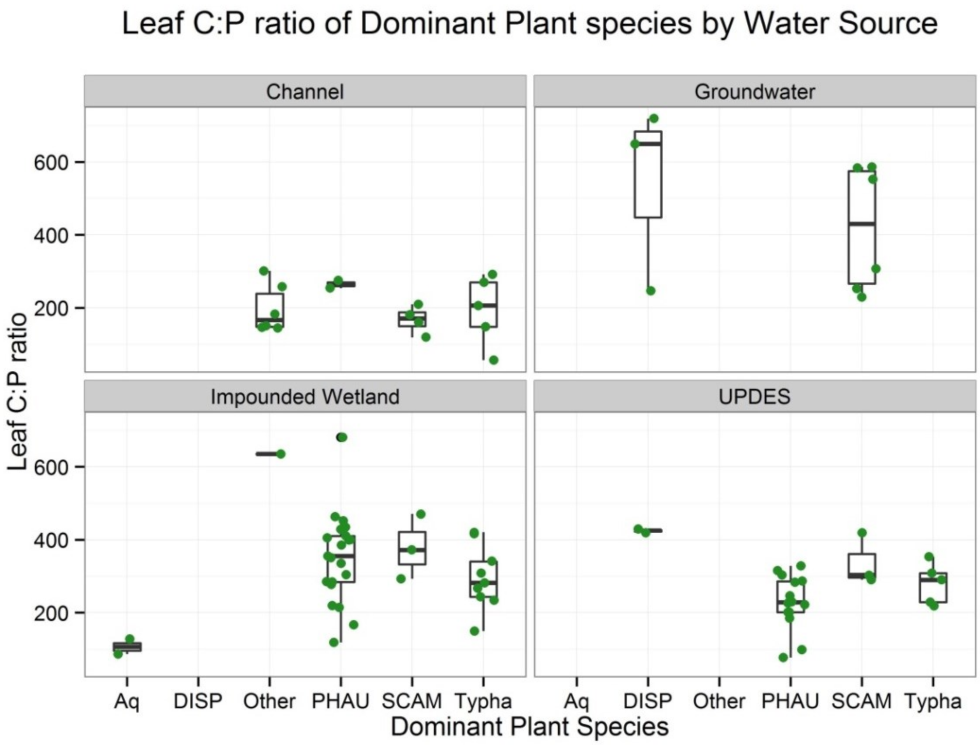

Figure 14. Leaf C:P ratio of dominant plant species, by water source

downstream of channels and impounded wetlands, particularly in comparison wetlands with groundwater inflows. Plants in groundwater-fed wetlands (*Distchlis* and S. *americanus*) have wider C:N ratios than the same species downstream of waste water treatment plants, consistent with the idea that nutrient availability is much greater in sites receiving treated wastewater effluent.

There is relatively greater variation in leaf C:P vs. C:N ratios among species and dominant water sources. The widest ranges among species are observed in sites downstream of impounded wetlands and wastewater treatment sites (Figure 14). For example, median species C:P values range from approximately 400:1 to 200:1 for aquatic species and *S. americanus*, respectively. Similarly, *Distchlis* has a C:P >600:1 and *Phragmites* near 200:1. The C:P of *Phragmites* appears to be lowest in sites associated with channels compared to sites below UPDES discharges or impounded wetlands. At a coarse scale, apparent differences in leaf N:P ratios are subtle (Figure 15), but appear to be more narrow (higher P availability) in UPDES sites compared to sites below impounded wetlands.

Finally, leaf $\delta^{15}N$ ratios can provide information about the relative importance of various N sources that are available for plant uptake. In Figure 16, plant $\delta^{15}N$ ratios are greater in sites receiving UPDES discharge relative to wetlands with other dominant water sources. This is most likely a consequence of the high degree of organic matter processing that occurs within modern waste water treatment facilities, where large portions of the N inputs to the waste stream are lost as gaseous products resulting from chemical and biological processes; these processes also happen to result in isotopic fractionation which produces the enriched $\delta^{15}N$ signal of the remaining material.

We also see evidence that leaf $\delta^{15}N$ ratios may vary with distance from the water inflows, at least in some system types (Figure 26). However, three of the four samples missing from the dataset are from the 100-m distance, from one site, that had the highest $\delta^{15}N$ signatures (Central Davis 01), such that the apparent increase in $\delta^{15}N$ could be due to a sample completeness issue. Figure 27 shows how differences in leaf $\delta^{15}N$ ratios between impounded wetland and UPDES water sources varied with distance along the wetland flowpath, for a single plant species

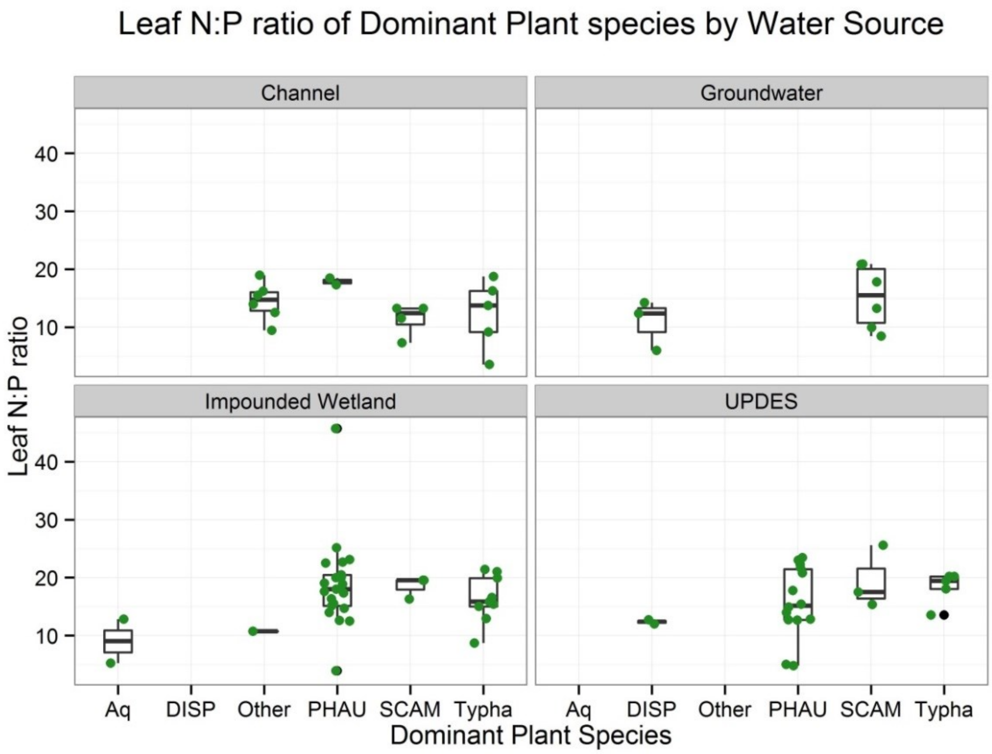

Figure 15. Leaf N:P ratio of dominant plant species, by water source.

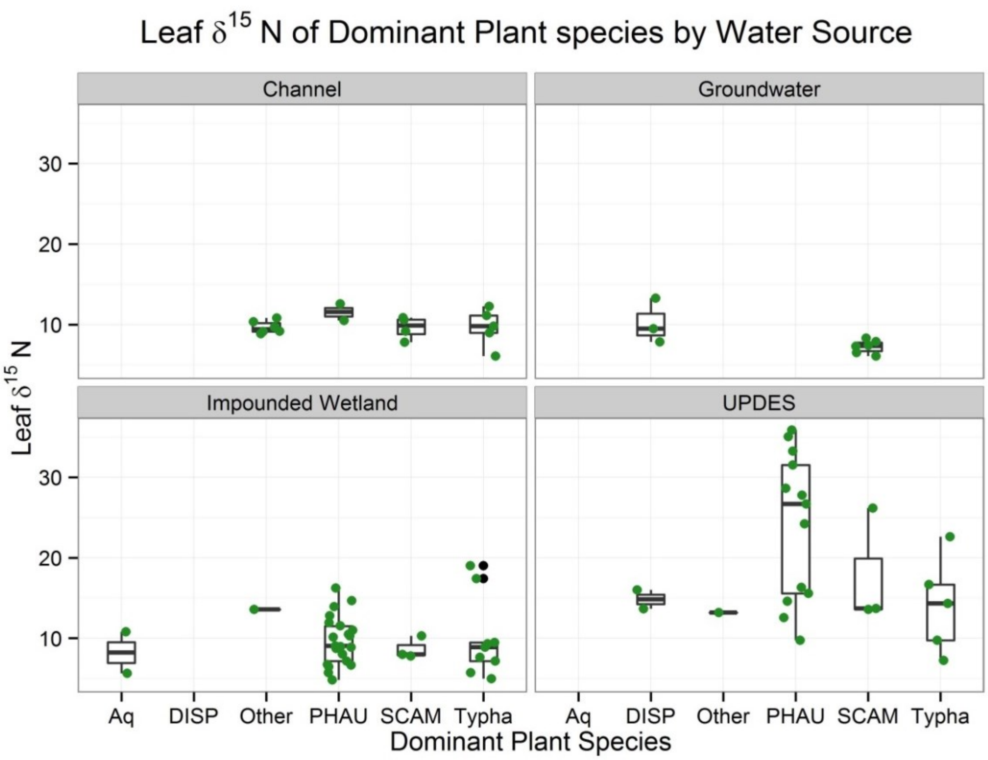

Figure 16. Leaf δ^{15}N isotope ratio for dominant plant species, by water source.

(*Phragmites australis*). Leaf $\delta^{15}N$ ratios were close to 30 ‰ in UPDES wetlands (Figure 27), a considerable enrichment compared to values near 10 ‰ for sites below impounded wetlands. Interestingly, while leaf $\delta^{15}N$ ratios were quite distinct between impounded wetland and UPDES water sources at 500 m from the inflow(Figure 27), leaf C:N ratios were very similar (Figure 28). This suggests that while the WWTP signal, as leaf $\delta^{15}N$ ratios, persists up to 500 m into these wastewater-dominated fringe wetlands, the effect of treated wastewater effluent on nutrient availability to emergent vegetation, as leaf C:N ratios, was attenuated at distances between 300 and 500 m from the inflow for the three fringe wetlands below UPDES facilities examined here.

5.0 Discussion

5.1 Preliminary metrics of interest

Given the limited number of sample sites (10 sites from 9 distinct water sources), only a limited list of potential metrics (or indicators) is proposed at this time, however, DWQ will sample fringe wetlands in 2015 as part of on-going wetland assessment projects. Metrics of ecological integrity (*condition*) or biological response to stress that appear promising at this early stage include:

- Vegetation-based metrics include cover of *Phragmites* (relative and total), relative cover of all invasive species, and plant species richness.
- Macroinverterate-based metrics include the relative dominance of Chironomids, particularly subfamily Chironominae (tribes Chironomini and Tanytarsini), and measures of invertebrate diversity.
- Water chemistry-based metrics could include the number of 'exceedences' of freshwater stream aquatic life use benchmarks, some integrative measure of aquatic metabolism (based on DO, pH, chlorophyll-a, etc.), or possibly a set of multi-metric indices for water column nutrients and soluble metals. The latter index could be based on an effects ratio of sample concentration vs. appropriate benchmarks.

With few exceptions, the same sampling scheme will be used in 2015 as 2013, with additional sites as well as repeat visits of some 2013 sites. In addition, DWQ will begin to incorporate elements from UGS's Utah Rapid Assessment Protocol (*unpublished*), which includes additional elements of site- and landscape-scale stress.

5.2 Lessons learned and next steps

A wide range of lessons were learned in 2013 during the sampling of GSL fringe wetlands. First, the hydrology of this wetland type is extremely variable in both time and space. After several years of drought and invasive species-related water management, extensive areas of emergent marsh lacked surface water – except for sites below nearby wastewater treatment plants. Second, sufficient numbers of macroinvertebrates to support diversity determinations can be collected by sampling more sweeps in inundated microsites/habitats that are hydrologically integrated with the site. Third, sample collection efforts can be improved by working with state agency and land management personnel to access remote areas of GSL. Fourth, identification, collection and analysis of data from potential reference standard sites, that lack significant urban, industrial and agricultural stresses, should improve our ability to detect biological response (signals) from the wide range of covariates and confounding factors (noise). Fifth, data from additional GSL-marsh sites, collected by other local researchers, will be examined for useful biological response or stressor metrics and possible inclusion in the fringe wetland dataset.

Next steps for fringe wetland assessment include continued field sampling from a wider range of sites, incorporation of reference standard site data into the dataset, and comparison of current results with historical data. In addition, DWQ will begin in-depth facilitated discussions with stakeholders on establishing water quality goals for Utah's wetlands, including designated uses for the major wetland classes associated with Great Salt Lake.

6.0 Literature Cited

Albert, D.A., D.A. Wilcox, J.W. Ingram, and T.A. Thompson. 2005. Hydrogeomorphic classification of Great Lakes coastal wetlands. J. Great Lakes Res. 31(suppl. 1): 129-146.

Alloway, B.J. (Ed.). 2012. Heavy metals in soils: trace metals and metalloids in soils and their bioavailability. 3rd Edition. Environmental Pollution Series, vol. 22. Springer, Dordrecht. 614 pp.

Arnow, T. 1984. Water-level and water-quality changes in Great Salt Lake, Utah, 1847-1983. U.S. Department of Interior, U.S. Geological Survey, circular 913. 29 pp. Online, accessed 1 March, 2015 (Link).

Brinson, M. 1996. Assessing wetland functions using HGM. National Wetlands Newsletter 18(1):10-16. Online, accessed 17 February, 2015 (Link)

CH2MHill. 2005. Statistical analyses of 2004 data on wetland plants and invertebrates in Farmington Bay, Great Salt Lake, Utah. Technical memo for Utah Division of Water Quality and Central Davis Sewer District. 62 pp. Online, accessed 19 February 2015, at: (Link).

CH2MHill. 2006. Analyses of 2005 data on wetland biota and water quality in Farmington Bay, Great Salt Lake, Utah. Technical memo for Central Davis Sewer District and Utah Division of Water Quality. 70 pp. Online, accessed 19 February 2015, at: (Link)

CH2MHill. 2012. A review: Farmington Bay hydrology and water management. Report to Utah Department of Natural Resources, Division of Forestry, Fire and State Lands. 60 pp. Online, accessed 18 February, 2015 at: (Link).

Cooper, M.J., G.A. Lamberti, and D.G. Uzarski. 2013. Spatial and temporal trends in invertebrate communities of Great Lakes coastal wetlands, with emphasis on Saginaw Bay of Lake Huron. J. Great Lakes Res. 40(suppl. 1): 168-182.

Cvetkovic, M., and P. Chow-Fraser. 2011. Use of ecological indicators to assess the quality of Great Lakes coastal wetlands. Ecological Indicators 11:1609-1622.

Dahl, T.E. 2006. Status and trends of wetlands in the conterminous United States, 1998 to 2004. U.S. Department of the Interior; Fish and Wildlife Service, Washington, D.C. 112 pp. Online, accessed 10 Jan., 2015 at: (Link)

Ducks Unlimited. 2008. Great Salt Lake Wetlands Assessment Project. GIS database. Online, accessed June 5, 2012 (Link)

Division of Water Quality, Utah (DWQ). 2009. *Development of an Assessment Framework for Impounded Wetlands of Great Salt Lake*. Great Salt Lake Water Quality Studies, November 2009. Accessed May 1, 2012; (Link).

Division of Water Quality, Utah (DWQ). 2012. Great Salt Lake Impounded Wetlands: 2012 Probabilistic Survey of Wetland Condition, Sampling and Analysis Plan. Online, accessed 2 February, 2015: (Link)

Division of Water Quality, Utah (DWQ). 2013. Great Salt Lake Wetlands (2013): Preliminary Fringe Wetland Condition Assessment, Sampling and Analysis Plan. Online, accessed 13 February, 2015: (Link)

Division of Water Quality, Utah (DWQ). 2014. Validation of and enhancements to an assessment framework for impounded wetlands of Great Salt Lake. Final Technical Memo, prepared by CH2MHill for Utah Department of Environmental Quality, Division of Water Quality. 57 pp. Online, accessed November 15, 2014: (Link).

Division of Water Quality, Utah (DWQ). 2015. Great Salt Lake Paleolimnological Study. Series of project reports for DWQ. Online, accessed 17 March, 2015: (Link)

Emerson, R. and T.D. Hooker. 2011. *Utah Wetland Functional Classification and Landscape Profile Generation within Bear River Bay, Great Salt Lake, Utah*. Utah Geological Survey, Salt Lake City, UT. Contract deliverable for EPA, Region 8 Wetlands Program. 39 pp.

Environmental Protection Agency (EPA). 2006. Guidance on systematic planning using the data quality objectives process. Office of Environmental Information. EPA/240/B-06/001: EPA QA/G-4. Online, accessed 1 March, 2015: (Link).

Hruby, T. 2001. Environmental Auditing: testing the basic assumption of the hydrogeomorphic approach to assessing wetland functions. Environmental Management 27(5): 749-761.

Jacobs, A.D., M.E. Kentula, and A.T. Herlihy. 2010. Developing an index of wetland condition from ecological data: an example using HGM functional variables from the Nanticoke watershed, USA. Ecological Indicators 10(3): 703-12.

Johnston, C.A., B.L. Bedford, M. Bourdaghs, T. Brown, C. Frieswyk, M. Tulbure, L. Vaccaro, and J.B. Zedler. 2007. Plant species indicators of physical environment in Great Lakes coastal wetlands. J. Great Lakes Res. 33(Spec. Iss. 3): 106-124.

Kadlec, R.H., and S.D. Wallace. 2009. Treatment Wetlands. 2nd Ed. CRC Press, Boca Raton. 1016 pp.

Keddy, P.A. 2010. *Wetland Ecology: Principles and Conservation*. 2nd edition. Cambridge University Press: New York. 497 pp.

King, R.S., and C.J. Richardson. 2002. Evaluating subsampling approaches and macroinvertebrate taxonomic resolution for wetland Bioassessment. J. N. Am. Benth. Soc. 21(1): 150-171.

Lemly, J. and L. Gilligan. 2013. Ecological Integrity Assessment (EIA) for Colorado wetlands. Field Manual, Ver. 1.0. Colorado Natural Heritage Program. 101 pp. Online, accessed 17 February, 2015: (Link).

Lougheed, V.L., C.A. Parker, and R.J. Stevenson. 2007. Using non-linear responses of multiple taxonomic groups to establish criteria indicative of wetland biological condition. Wetlands 27(1): 96-109.

McCune, B., and M.J. Mefford. 2011. PC-ORD. Multivariate analysis of ecological data. Ver. 6.0. MjM Software, Gleneden Beach,Oregon, USA. URL: http://home.centurytel.net/~mjm/pcordwin.htm.

Menuz, D., R. Sempler, and J. Jones, 2014. Great Salt Lake Wetland Condition Assessment. Utah Geological Survey. Contract deliverable to U.S. EPA Wetland Program Development Grant. Online, accessed May, 2014 at: (Link).

Millennium Ecosystem Assessment. 2005. *Ecosystems and Human Well-being: Wetlands and Water Synthesis*. World Resource Institute. Washington, D.C. 80 pp.

Miller, T.G., and H. M. Hoven. 2007. *Ecological and Beneficial Use Assessment of Farmington Bay wetlands: Assessment and Site-specific Nutrient Criteria Methods Development, Phase I*. Progress Report to EPA, Region 8, for Wetland Program Development Grant No: CD988706-03. Accessed May 2012: (Link).

Miller, T.G., H.M. Hoven, J. Cavitt, and L. Gray. 2012. *Research Compendium, Jordan River and Farmington Bay Water Quality Council, Utah*.

Mitsch, W.J. and J.G. Gosselink. 2007. *Wetlands*. 4th edition. Wiley & Sons: Hoboken, New Jersey. 582 pp.

National Wetlands Inventory (NWI). 2008. Wetlands Data for Utah (GIS data). United States Fish and Wildlife Service. Accessed March 2010: (Link).

R Core Team. 2014. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL: http://www.R-project.org/.

Reddy, K.R., and R.D. DeLaune. 2008. Biogeochemistry of Wetlands. CRC Press, Boca Raton. 774 pp.

Rocchio, F.J., and R.C. Crawford. 2013. Floristic quality assessment for Washington vegetation. Washington Natural Heritage Program. 55 pp. Online, accessed 17 February, 2015: (Link).

Smith, R.D., A. Ammann, C. Bartoldus, and M.M. Brinson. 1995. *An Approach for Assessing Wetland Functions Using Hydrogeomorphic Classification, Reference Wetlands, and Functional Indices*. Technical Report WRP-DE-9, United States Army Engineer Waterways Experiment Station: Vicksburg, Mississippi. 90 pp.

Stein, E.D., A.E. Fetscher, R.P. Clark, A. Wiskind, J.L. Grenier, M. Sutula, J.N. Collins, and C. Grosso. 2009a. Validation of a wetland rapid assessment method – use of EPAs level 1-2-3 framework for method testing and refinement. Wetlands 29(2): 648-665.

Stein, E.D., M. Brinson, M.C. Rains, W. Kleindl, and F.R. Hauer. 2009b. Wetland Assessment Debate: Wetland assessment alphabet soup: how to choose (or not choose) the right assessment method. Wetland Science and Practice 26(4): 20-24. Online, accessed 17 February, 2015: (Link).

Steinman, A.D., M.E. Ogdahl, M. Weinart, and D.G. Uzarski. 2014. Influence of water-level fluctuation duration and magnitude on sediment-water nutrient exchange in coastal wetlands. Aquatic Ecology 48: 143-159.

Stevens, D.L., and S.F. Jensen. 2007. Sample design, execution, and analysis for wetland assessment. Wetlands 27(3):515–523.

Sumner, R., J. Schubauer-Berigan, T. Mulcahy, J. Minter, B. Dyson, C. Godfrey, and J. Blue. 2010. Alternative futures analysis of Farmington Bay wetlands in the Great Salt Lake ecosystem. EPA, Cincinnati, OH. EPA/600/R-10/032. 106 pp. Online, accessed 13 February, 2015: (Link)

Wardrop, D.H., M.E. Kentula, S.F. Jensen, D.L. Stevens, K.C. Hychka, and R.P. Brooks. 2007. Assessment of wetlands in the upper Juniata watershed in Pennsylvania, USA using the hydrogeomorphic approach. Wetlands 27(3): 432-445.

Ye, R., A.L. Wright, W.H. Orem, and J.M. McCray. 2010. Sulfur distribution and transformations in Everglades Agricultural Area soil as influenced by sulfur amendment. Soil Science 176(6): 263-269.

7.0 Appendix -- Additional figures to accompany text

Example of two species patterns from preliminary Vegetation-NMDS results

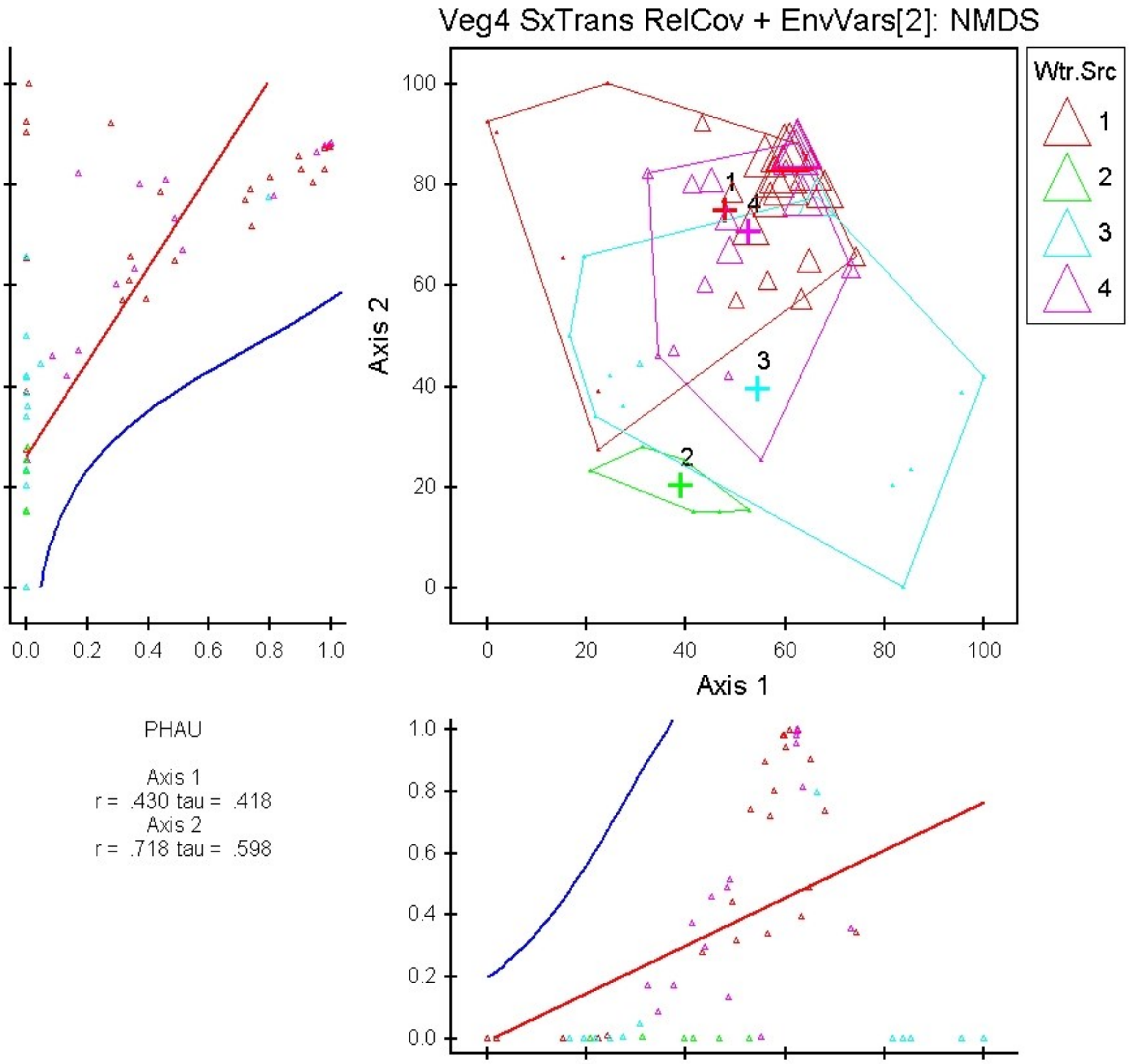

Figure 17. Correlation between *Phragmites australis* relative abundance and Veg-NMDS scores.

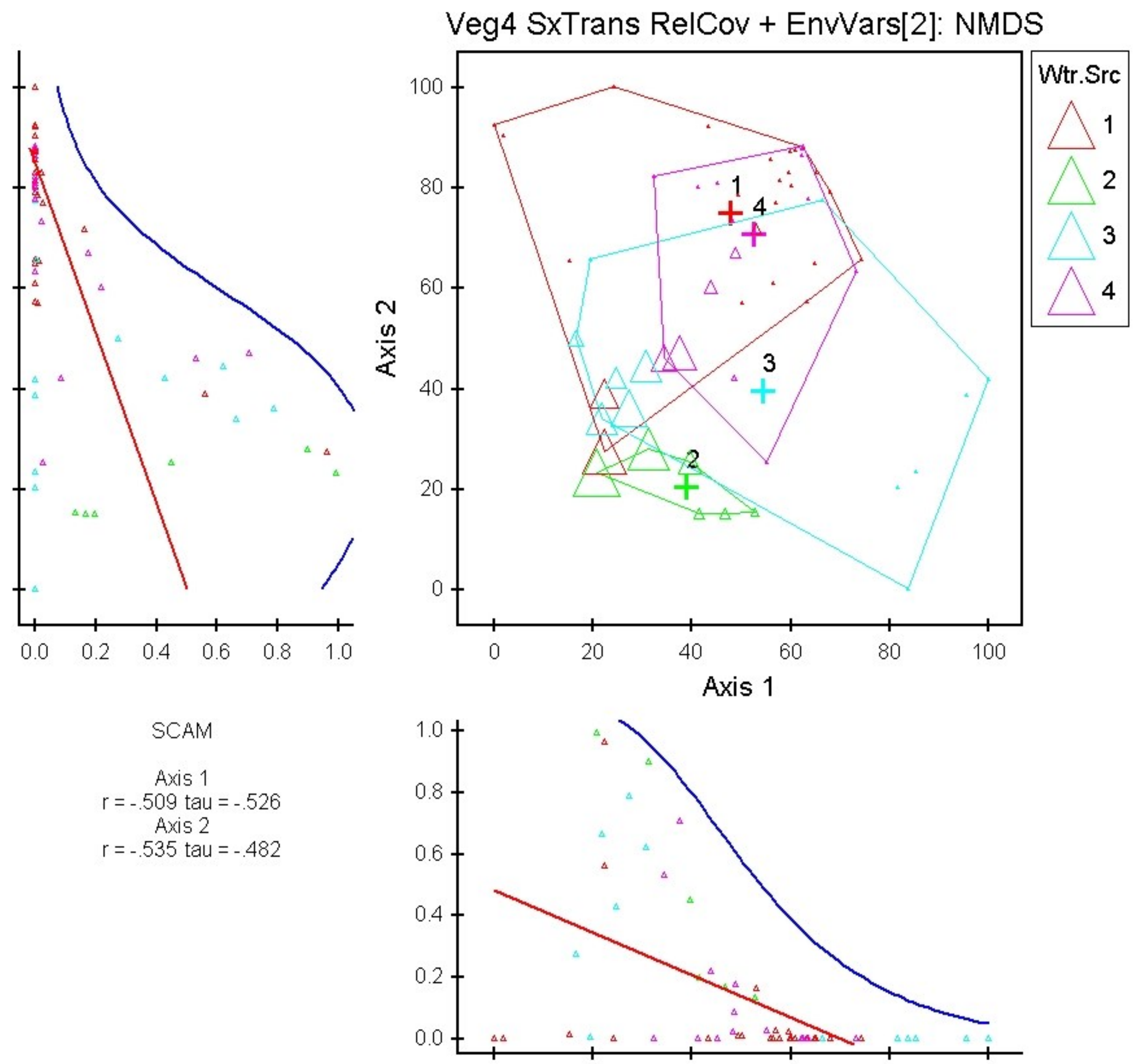

Figure 18. Correlation between *Schoenoplectus americanus* relative abundance and Veg-NMDS scores.

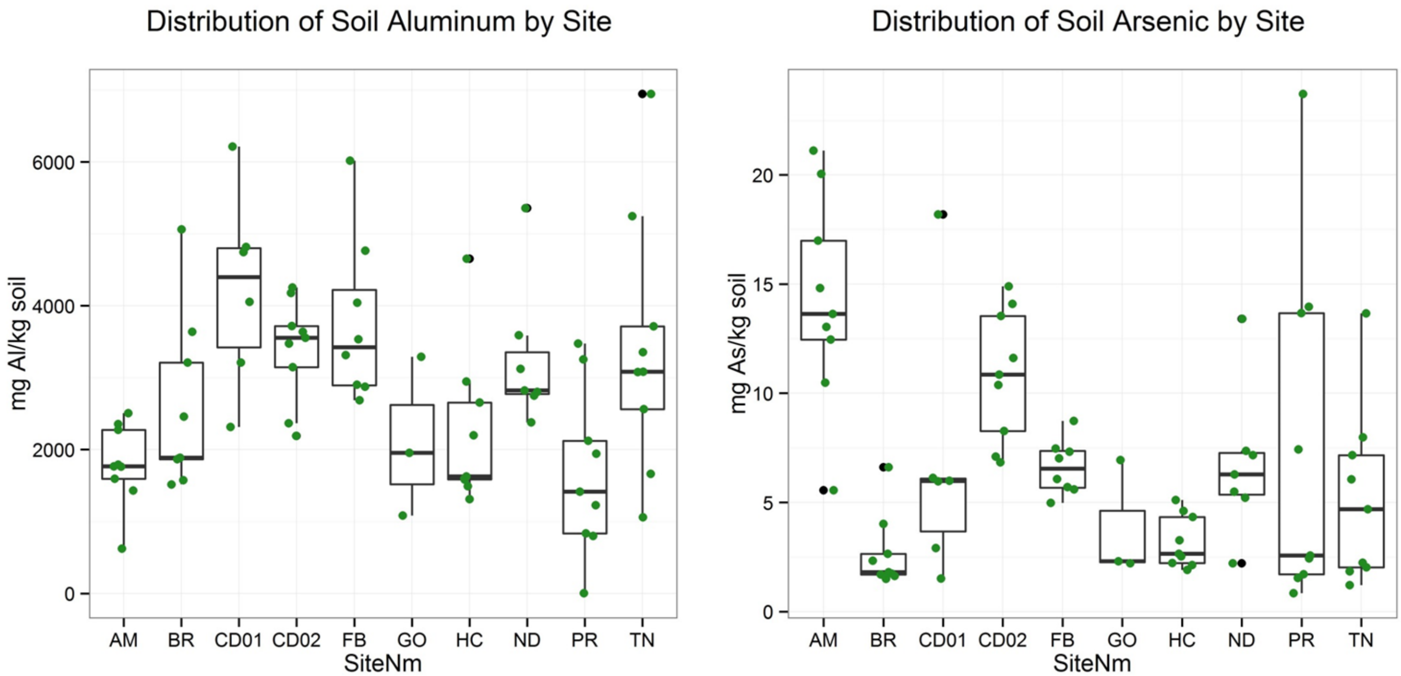

Figure 19. Distribution of soil Aluminum and Arsenic by site.

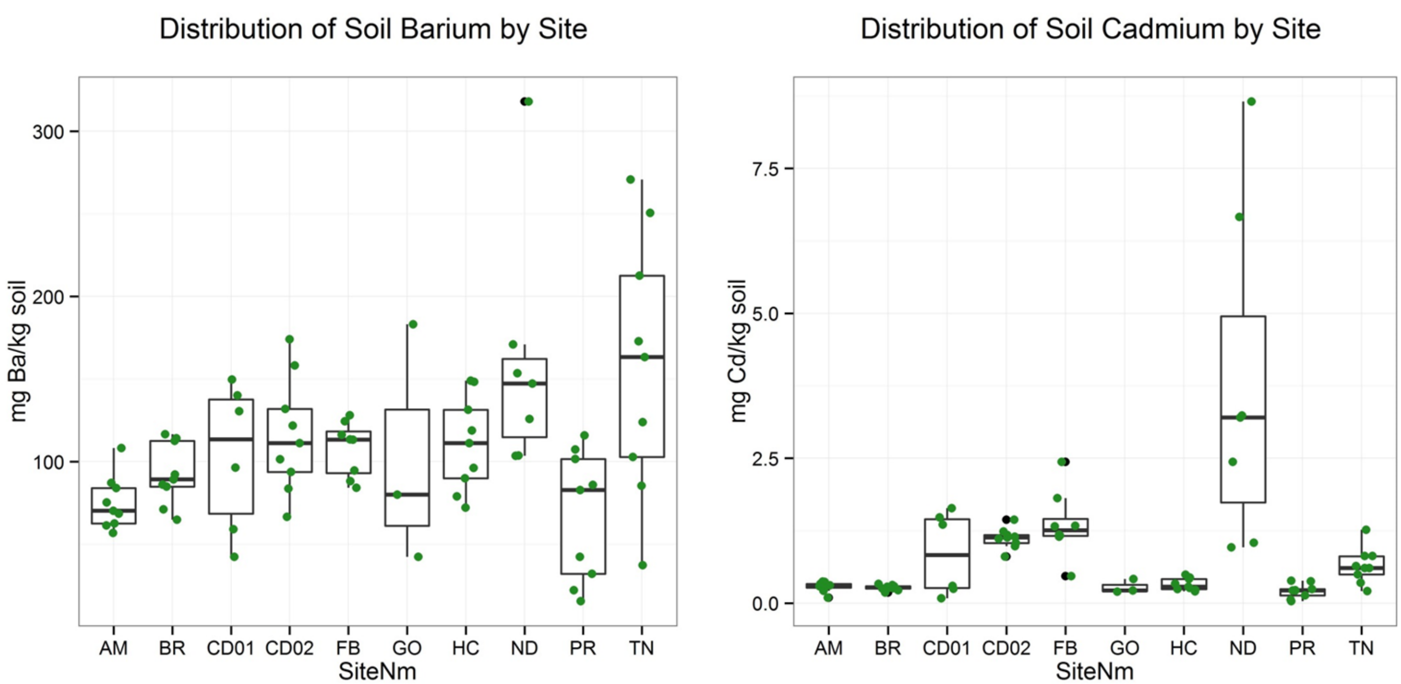

Figure 20. Distribution of soil Barium and Cadmium by site.

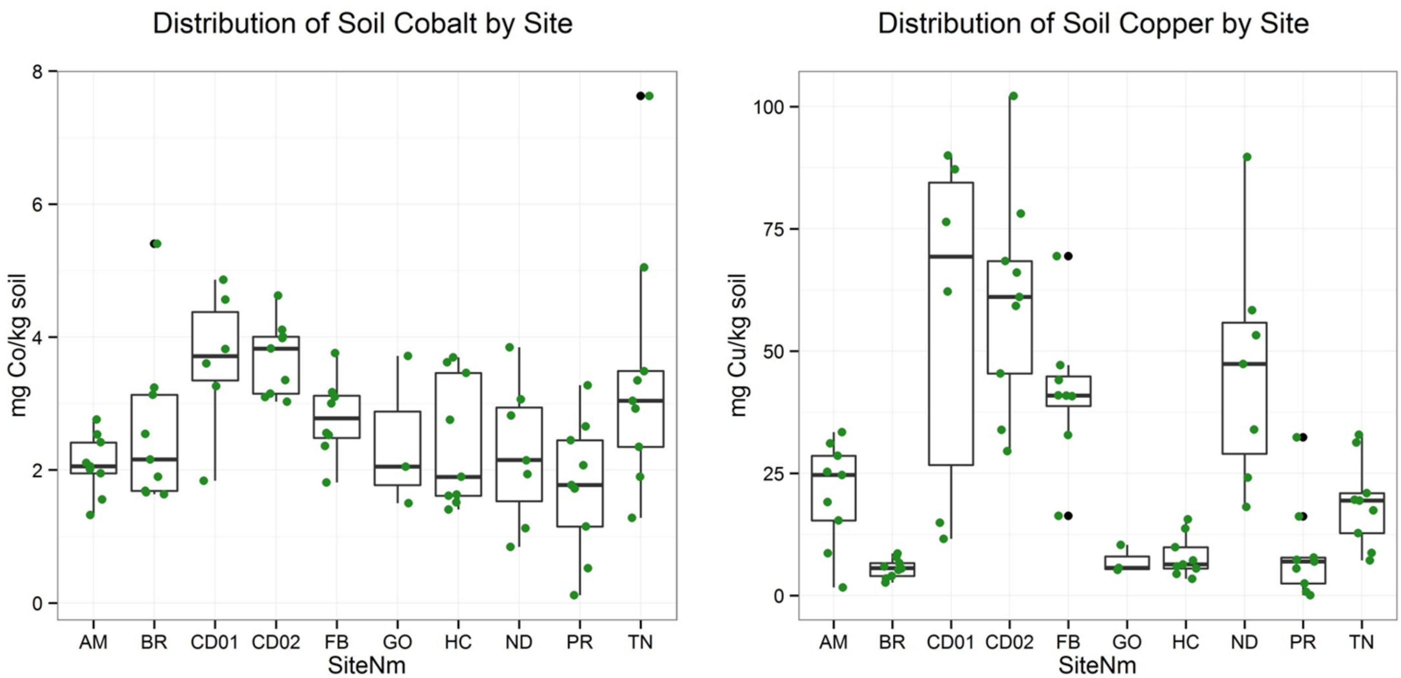

Figure 21. Distribution of soil Cobalt and Copper by site.

Figure 22. Distribution of soil Iron and Manganese by site.

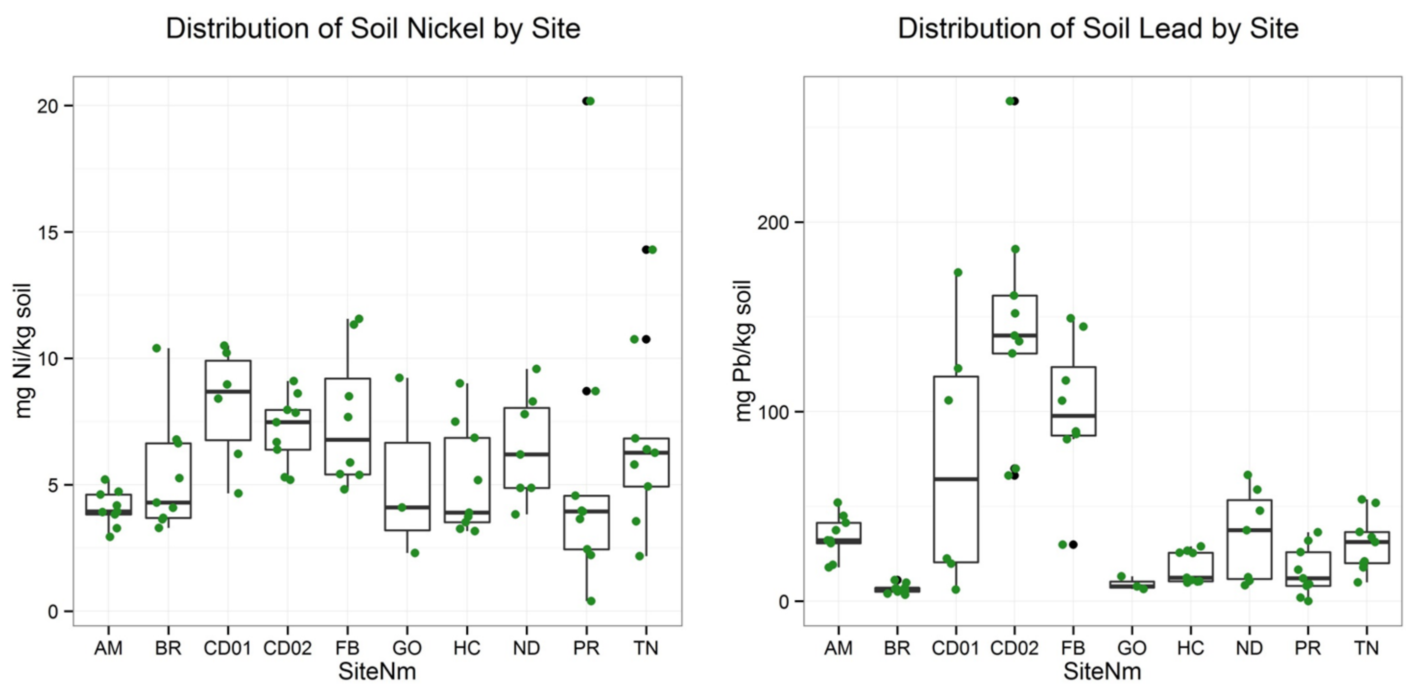

Figure 23. Distribution of soil Nickel and Lead by site.

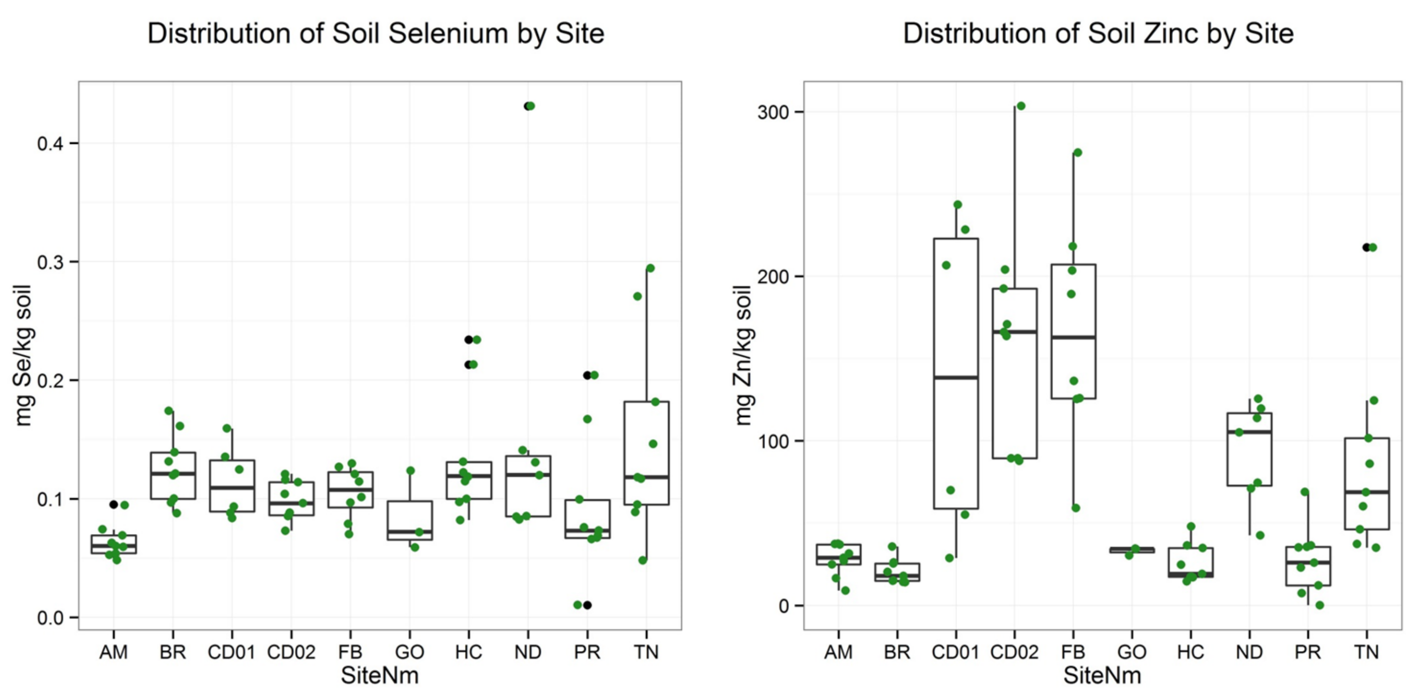

Figure 24. Distribution of soil Selenium and Zinc by site.

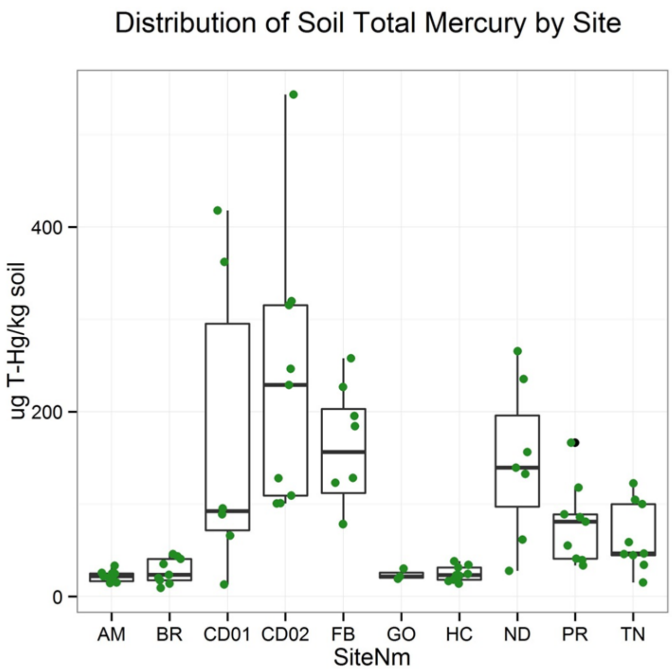

Figure 25. Distribution of soil Total Mercury by site.

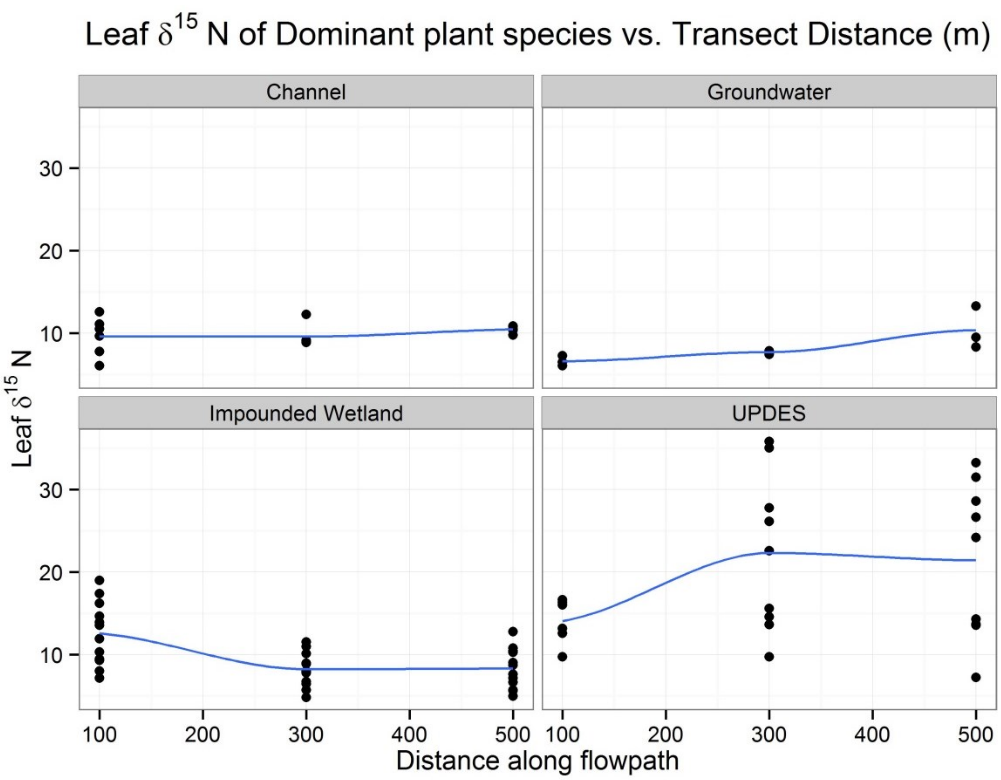

Figure 26. Leaf $\delta^{15}N$ signatures of dominant plant species vs. distance from water inflow.

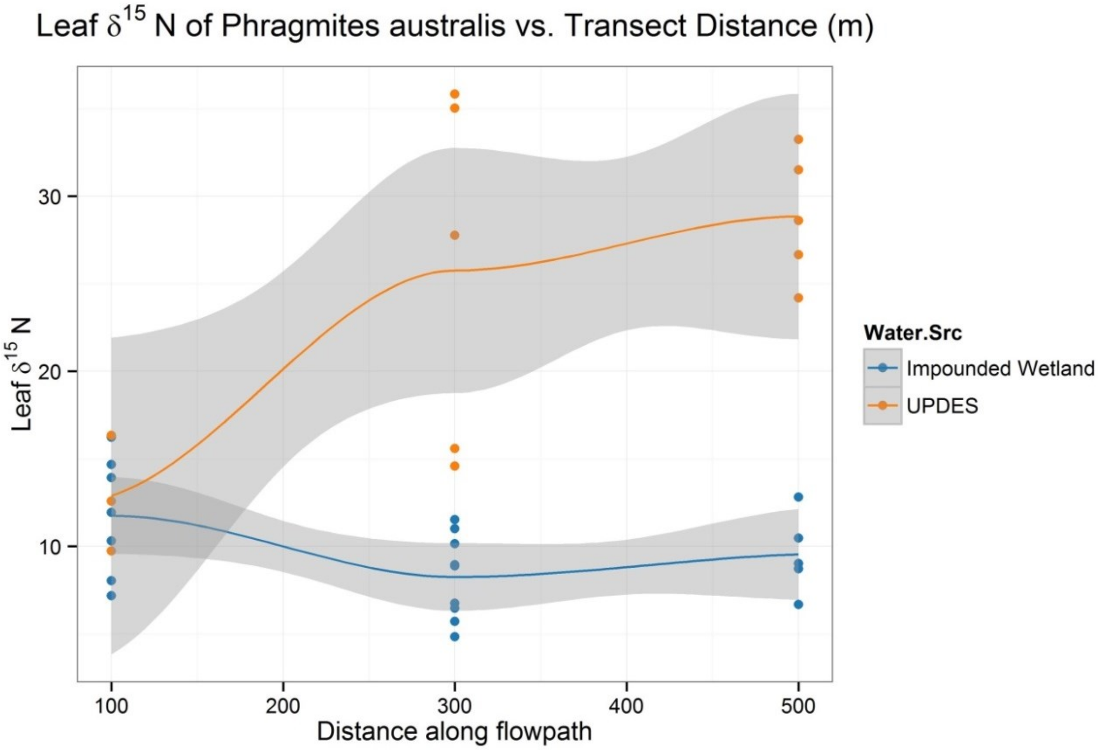

Figure 27. Leaf $\delta^{15}N$ signatures of *Phragmites australis* vs. distance from water inflow.

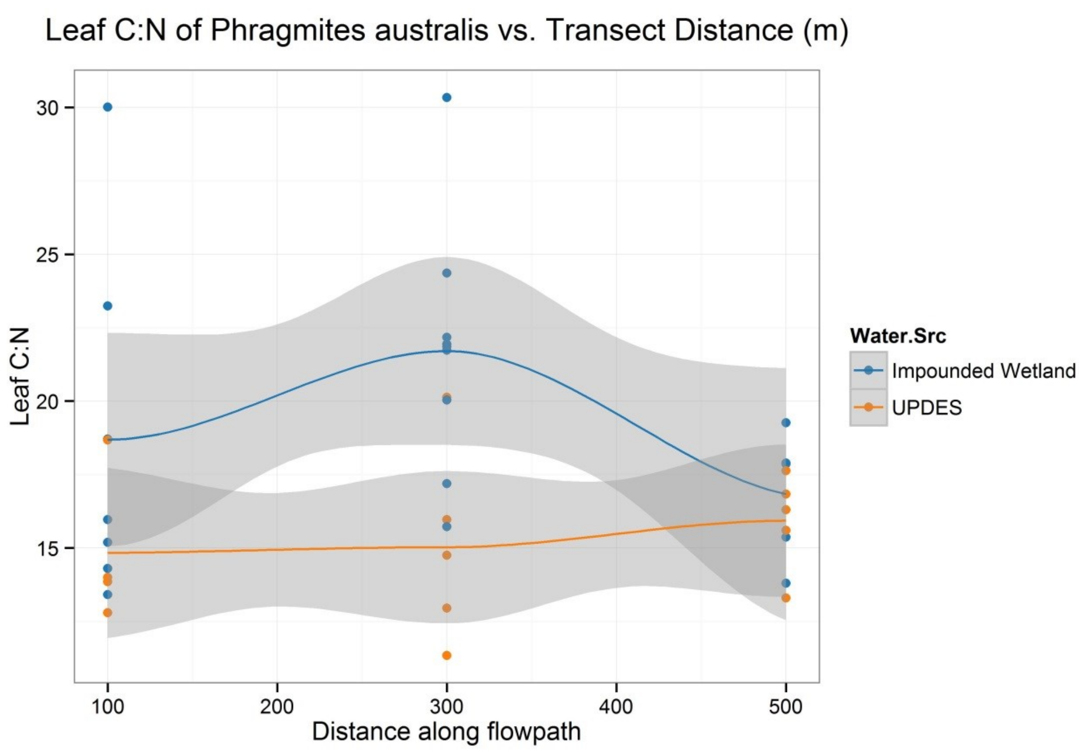

Figure 28. Leaf C:N ratios of *Phragmites australis* vs. distance from water inflow.

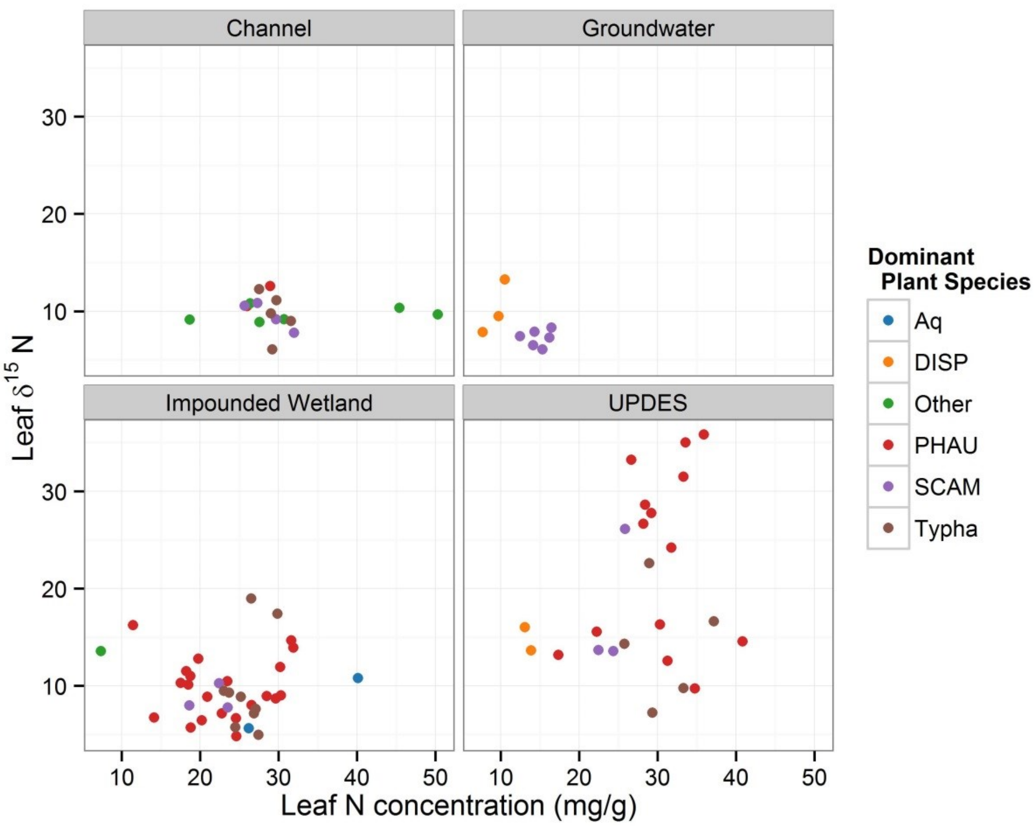

Figure 29. Leaf δ^{15}N ratio as a function of Leaf N concentration, for dominant plant species and water sources.

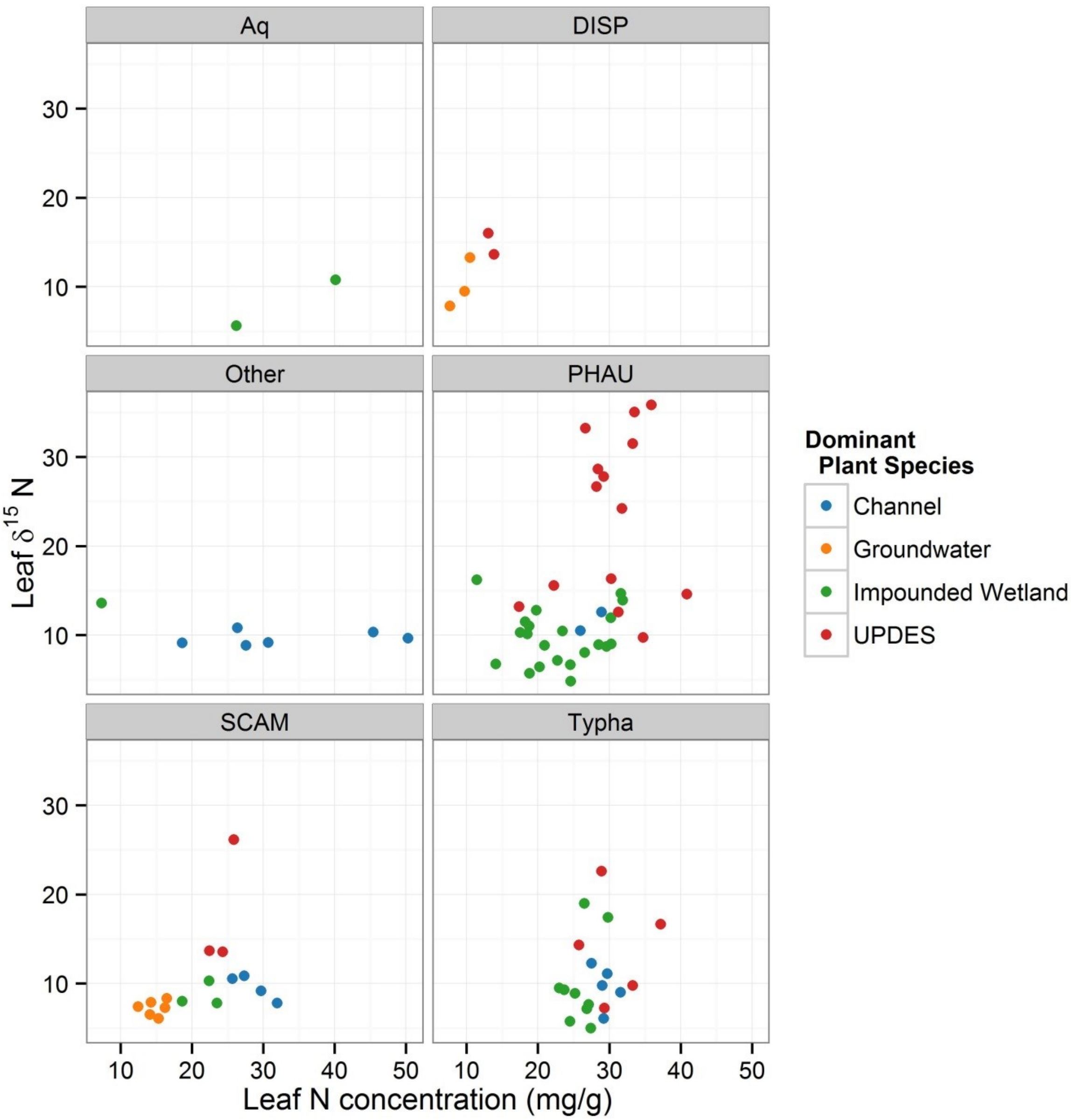

Figure 30. Leaf δ[15]N ratio as function of Leaf N concentration, for dominant water sources and plant species.